frontiers | Research Topics

Sports medicine and physical rehabilitation, volume III

Edited by
David Levine, Arielle Pechette Markley, Heidi Reesink
and Denis J. Marcellin-Little

Published in
Frontiers in Veterinary Science

ISSN 1664-8714
ISBN 978-2-8325-6068-6
DOI 10.3389/978-2-8325-6068-6

About Frontiers

Frontiers is more than just an open access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers journal series

The Frontiers journal series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the *Frontiers journal series* operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews. Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the *Frontiers journals series*: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area.

Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers editorial office: frontiersin.org/about/contact

Sports medicine and physical rehabilitation, volume III

Topic editors
David Levine — University of Tennessee at Chattanooga, United States
Arielle Pechette Markley — Red Sage Integrative Veterinary Partners, United States
Heidi Reesink — Cornell University, United States
Denis J. Marcellin-Little — University of California, Davis, United States

Citation
Levine, D., Pechette Markley, A., Reesink, H., Marcellin-Little, D. J., eds. (2025). *Sports medicine and physical rehabilitation, volume III*. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-8325-6068-6

Table of contents

frontiers | Frontiers in Veterinary Science

TYPE Editorial
PUBLISHED 19 February 2025
DOI 10.3389/fvets.2025.1551208

Check for updates

OPEN ACCESS

EDITED BY
Roger Kenneth Whealands Smith,
Royal Veterinary College (RVC),
United Kingdom

REVIEWED BY
Andris J. Kaneps,
Kaneps Equine Sports Medicine and Surgery,
United States
Jane Manfredi,
Michigan State University, United States

*CORRESPONDENCE
Denis J. Marcellin-Little
✉ djmarcel@ucdavis.edu

RECEIVED 24 December 2024
ACCEPTED 07 February 2025
PUBLISHED 19 February 2025

CITATION
Levine D, Pechette Markley A,
Marcellin-Little DJ and Reesink H (2025)
Editorial: Sports medicine and physical
rehabilitation, volume III.
Front. Vet. Sci. 12:1551208.
doi: 10.3389/fvets.2025.1551208

Editorial: Sports medicine and physical rehabilitation, volume III

David Levine[1], Arielle Pechette Markley[2], Denis J. Marcellin-Little[3]* and Heidi Reesink[4]

[1]Department of Physical Therapy, University of Tennessee at Chattanooga, Chattanooga, TN, United States, [2]Red Sage Integrative Veterinary Partners, Fort Collins, CO, United States, [3]Department of Surgical and Radiological Sciences, University of California, Davis, Davis, CA, United States, [4]Department of Clinical Sciences, College of Veterinary Medicine, Cornell University, Ithaca, NY, United States

KEYWORDS

veterinary rehabilitation, rehabilitation, sports medicine, orthopedics, canine rehabilitation, equine rehabilitation, veterinary sports medicine, neurology—dog

Editorial on the Research Topic
Sports medicine and physical rehabilitation, volume III

Veterinary *Sports Medicine and Physical Rehabilitation* is now a well-established field. The articles in the first and second volumes of the Veterinary *Sports Medicine and Physical Rehabilitation* ebooks, published by Frontiers in Veterinary Science, have been viewed more than 175,000 times and have been downloaded more than 32,000 times.

This Research Topic is the third volume in the series and includes 15 research articles by 50 authors focusing on sports medicine (seven articles) and physical rehabilitation (eight articles).

Two articles focused on the management of orthopedic problems in horses. A study by Hallowell et al. evaluated the systemic absorption of triamcinolone after intrasynovial (antebrachiocarpal) and extrasynovial (sacroiliac) injection. The study also evaluated the effects of triamcinolone absorption on glucose, insulin, cortisol, and adrenocorticotropic hormone. Intrasynovial injections led to increased plasma triamcinolone levels 8 to 36 h after injection. Insulin and glucose were also elevated after injection. No adverse reactions were noted and all horses had normal physical examination parameters throughout the study period. This study suggests that more work is needed to investigate risk factors for corticosteroid-associated laminitis in horses. A study by Gruyaert et al. evaluated the proximity of needles placed for palmar digital nerve blocks to nearby synovial structures using computed tomography. The majority of (97%) needles avoided synovial penetration, but the risk of synovial penetration was higher when needle placement was distal and when synovial structures were distended. Clinicians should be aware that there is a low risk of inadvertent penetration of the distal interphalangeal joint, navicular bursa, or digital flexor tendon sheath when performing palmar digital perineural anesthesia.

Thirteen articles focused on the management of orthopedic or neurologic problems in dogs. A 45-day clinical trial by Talsma et al. evaluated the efficacy of cannabidiol in dogs with mobility disorders and assessed the safety of the cannabidiol in combination with a non-steroidal anti-inflammatory drug (NSAID). Subjective outcome measures, including client questionnaires and blinded veterinary assessments, improved over the course of the study, but greater ALP elevations were seen in dogs receiving combination therapy with an NSAID. Further research is needed to better understand the safety and efficacy of CBD when administered with NSAIDs and other medications.

Two rehabilitation articles evaluated extracorporeal shockwave therapy. A clinical trial by Joseph et al. compared the noise reactivity and tolerance to treatment between a standard and a novel trode designed to reduce the peak focal energy used to deliver the extracorporeal shockwave therapy. Dogs tolerated the novel trode better, allowing the delivery of 10% more shocks at a 20% higher energy level. In a case series, Tsai and Alvarez described the response to extracorporeal shockwave therapy and physical rehabilitation in working dogs with fibrotic myopathy. On average, dogs were able to return to work for ∼3 years after the time of diagnosis, a more favorable outcome than the outcome described in the previous case series.

A study by Blake et al. described the kinetic parameters of dogs walking across cavaletti rails at heights of 5, 10, 15, and 20 cm (2, 4, 6, and 8 inches). Increasing cavaletti rail height resulted in a decrease in gait velocity and an associated increase in gait cycle duration. A clinical study by Schwartz et al. evaluated gluteal and quadriceps femoris muscle activation using surface electromyography in dogs recovering from hemilaminectomy compared to normal dogs. Muscle activation was increased by more than 30% in the operated dogs compared to normal dogs and was 30% less on the operated side than on the unoperated side. The greater muscle activity in the group that underwent hemilaminectomy may be explained by hypertonia, but making comparisons of EMG findings between dogs is inherently problematic because of potential differences in electrode placement.

Narum et al. surveyed 1,221 caretakers of dogs using an assistive mobility cart to evaluate quality of life, function, and adverse events. With the use of a mobility cart, ∼60% of caretakers reported improvement in the quality of life of their dog or cat. More than 60% of the animals experienced an adverse event and half of those were wounds. This study was the largest of its kind and provided helpful information to pet caretakers and clinicians. A study by Christie et al. evaluated the agreement in body condition and muscle condition when a group of working dogs was evaluated by one handler and three veterinarians. Handlers appeared to have a higher likelihood of rating their dogs as optimally conditioned and muscled than veterinarians. This project emphasized the importance of standardizing training and guidelines for the assessment of body and muscle condition in working dogs.

Six articles focused on sporting dogs. A retrospective study by Hattendorf et al. summarized the injuries sustained by ∼1,000 Alaskan and Siberian husky sled dogs during a 1,000-mile (1,600-km) sled dog race. Approximately half of the dogs had a medical problem during the race and one-third sustained an orthopedic injury. Carpal and shoulder injuries were most common. Five studies focused on agility dogs. One survey study by Alva et al. evaluated the outcome of perceived limb injuries in agility dogs. Owners sought veterinary care more than 80% of the time and often sought specialty care. Rest was the most common treatment used. Two-thirds of the dogs returned to sport within 3 months of perceived injury, although dogs with stifle injuries reported a longer time to return to sport. A survey study by Kieves et al. evaluated risk factors for stifle injuries in agility dogs. Five factors were associated with an increased risk of stifle joint injury: being heavier, being a Border Collie, being a male and neutered before 10 months of age, being a female and spayed before the first heat cycle, having an 18- to 24-year-old handler, and teeter contact behavior. The biomechanics of agility dogs negotiating the teeter, a dynamic agility contact obstacle were further evaluated in a study by Pechette Markley, Wood, et al.. In this study, dogs used various strategies to negotiate the teeter. The study provided insight into these strategies, opening the door for further research focused on dynamic stability and postural control. Another study by Pechette Markley, Kieves, et al. investigated the effects of the ground surface (dirt, grass, or sand) on speed during agility trials. Trials run on sand were slower than trials run on grass or dirt. This study highlights the need for kinetic and kinematic studies comparing surfaces in agility events and how these may relate to injury risk. A study by Sellon et al. described the methodology for developing a rating of perceived exertion (RPE) tool to help quantify training load in agility dogs. RPE is widely used in the training of human athletes and this research adapted the tool for use in agility dogs. The tool was quick and easy to use but requires validation.

Like the first two volumes, this third ebook volume on *Sports Medicine and Physical Rehabilitation* will be a valuable resource for veterinary rehabilitation and sports medicine professionals. The Editors are pleased with the strength and diversity of the 15 articles included in this volume. They provide valuable information for veterinary sports medicine and physical rehabilitation practitioners and provide a foundational context for future research in the field.

Author contributions

DL: Writing – original draft, Writing – review & editing. AP: Writing – original draft, Writing – review & editing. DM-L: Writing – original draft, Writing – review & editing. HR: Writing – original draft, Writing – review & editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

frontiers | Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 09 August 2023
DOI 10.3389/fvets.2023.1249592

Check for updates

OPEN ACCESS

EDITED BY
Denis J. Marcellin-Little,
University of California, Davis, United States

REVIEWED BY
Matthew Warren Brunke,
Veterinary Referral Associates, United States
Ronald Koh,
University of California, Davis, United States

*CORRESPONDENCE
Lindsay H. Elam
✉ lindsay.elam@colostate.edu

RECEIVED 28 June 2023
ACCEPTED 25 July 2023
PUBLISHED 09 August 2023

CITATION
Joseph GL, Duerr FM, Zhou T and Elam LH (2023) Use of a novel shockwave trode results in better patient acceptance in awake canine patients treated for musculoskeletal disease. *Front. Vet. Sci.* 10:1249592.
doi: 10.3389/fvets.2023.1249592

Use of a novel shockwave trode results in better patient acceptance in awake canine patients treated for musculoskeletal disease

Gina L. Joseph[1], Felix M. Duerr[1], Tianjian Zhou[2] and Lindsay H. Elam[1]*

[1]Department of Clinical Sciences, Colorado State University, Fort Collins, CO, United States,
[2]Department of Statistics, Colorado State University, Fort Collins, CO, United States

Introduction: Extracorporeal shockwave therapy (ESWT) is used as a treatment option for several musculoskeletal pathologies in dogs. When performing ESWT using electrohydraulic devices, sedation is commonly recommended due to the noise and discomfort associated with the treatment. The aim of this study was to compare the tolerance of ESWT delivered by a standard or novel trode in awake canine patients with musculoskeletal disease.

Materials and methods: This was a prospective, blinded clinical trial in which dogs with musculoskeletal disease received awake treatment with ESWT with a gradually increasing energy protocol using both standard and novel trodes with an electrohydraulic generator in a randomized fashion. Noise reactivity and tolerance to treatment as measured in number of shocks and energy level achieved were recorded.

Results: Forty client-owned dogs with pathology affecting the hips, stifles, elbows, or shoulders were enrolled. Thirty-three dogs completed all three treatment sessions, three dogs completed two sessions, and four dogs completed one session. There was evidence of improved patient tolerability with the novel trode, based on an increased average number of shocks delivered ($n \pm SD = 848 \pm 334$ for novel trode; $n \pm SD = 767 \pm 358$ for standard trode; $p = 0.0384$) and higher average treatment energy level achieved ($E \pm SD = 6.5 \pm 2.5$ for novel trode; $E \pm SD = 5.3 \pm 2.8$ for standard trode; $p = <0.001$). Decreased noise reactivity was found to be positively correlated with tolerability of shockwave treatment (energy level: $p = 0.0168$; number of shocks: $p = 0.0097$).

Discussion: Administration of electrohydraulic ESWT is feasible in select awake patients using a gradually increasing energy protocol, and the tested novel shockwave trode is better tolerated than the standard trode. Further studies are required to determine the efficacy of the novel trode, and if gradually increasing energy protocols are clinically equivalent to current standard protocols that employ a consistent energy level.

KEYWORDS

canine, musculoskeletal, extracorporeal, shockwave, orthopedic, awake

1. Introduction

Extracorporeal shockwave therapy (ESWT) was developed in the 1970s as a non-invasive method for treating kidney and bladder stones in humans (1). Its use has since extended beyond lithotripsy, and it is now used for a number of orthopedic conditions (2, 3). In canines, ESWT is used to treat elbow, stifle and hip osteoarthritis (4–8), and shoulder tendinopathies (9–12). In addition, ESWT has been shown to accelerate bone healing (13) and improve weight bearing after tibial plateau leveling osteotomy (14).

Shockwave therapy can be delivered as either a focused pressure wave or an unfocused, radial wave (3). Focused shockwaves can be generated via three different types of energy sources: electromagnetic, electrohydraulic, and piezoelectric (15, 16). Each focused shockwave is generated in a handpiece, termed a trode, and delivered into tissues through a coupling medium. When the shockwaves encounter an interface with a change in tissue density, such as between bone, tendon, or ligament, they stimulate mechanotransduction. This has been suggested to lead to increased vascularization, the promotion of collagen production and organization, and tissue regeneration (15, 16). Shockwaves are engineered to reach a targeted tissue depth which varies between generation methods, machines, and trodes. Standard electrohydraulic shockwave machines tend to generate a higher acoustic energy wave that can penetrate more deeply into tissues (3).

Many manufacturers recommend the use of ear plugs and sedation for the patients due to the discomfort and noise produced during treatment (3). To the authors' knowledge, the currently published research involving focused shockwave in canines have all been performed under sedation or general anesthesia, however anecdotally in dogs and horses, treatments have been administered without sedation (3). While generally safe when appropriate protocols are applied, sedation is not without risk to the patient and involves additional time and cost demands of the client and veterinary staff (17–23). While shockwave therapy has been associated with minor adverse side effects, the main risk of severe complications associated with the treatment results from the sedation. These factors have led manufacturers to develop new methods of shockwave generation and delivery to canine patients. One such method involves increasing the focal dimensions over which the energy is delivered (24, 25). A recently released novel trode is proposed to decrease local discomfort at the skin-trode interface while still delivering focused energy to the tissues and increasing the volume of treated tissues. However, to the authors' knowledge, it is currently unknown if this novel trode would allow for treatment without sedation. Therefore, the aim of this study was to compare the tolerance of ESWT delivered by an electrohydraulic generator using a standard and novel shockwave trode in awake canine patients with musculoskeletal disease affecting the hips, stifles, elbows, or shoulders.

2. Materials and methods

This was a prospective, blinded, randomized clinical trial, and the study design was approved by the Institutional Animal Care and Use Committee and Clinical Review Board (IACUC: #1744 at Colorado State University) and all institutional regulations and guidelines were followed. Client-owned dogs weighing at least 10 kg with confirmed musculoskeletal disease affecting the hips, stifles, elbows, or shoulders were recruited. Owners were informed of the study requirements and consented to treatment at the time of enrollment. Musculoskeletal disease was confirmed prior to enrollment via review of available diagnostic imaging (radiographs, ultrasound, and/or computed tomography). Participation in the study was only offered if the primary clinician determined that the patient would benefit from extracorporeal shockwave therapy and the owners were interested in pursuing treatment. Patients were excluded if they had septic, immune-mediated or neoplastic disease affecting the joint(s) to be treated. Patients were also excluded if they had behavioral conditions requiring medications, were on any behavior modifying medications, had been sedated within 24 h, or were not amenable to gentle handling/restraint techniques. Specifically, dogs that were overly aggressive or fearful on preliminary exam or would hide and refuse to leave the corner of the exam room were excluded.

TABLE 1 Trode Order Protocol Allocation.

Number on die	Treatment protocol
1	NNS
2	NSN
3	SNN
4	SSN
5	SNS
6	NSS

S, standard trode; N, novel trode.

Dogs received treatment with both a standard and novel trode for a total of three treatments. Each treatment was performed ∼2–4 weeks apart. Three treatments were chosen because it falls within the current protocol at the authors' institution and allowed for blinding of the single observer (i.e., to avoid knowing the following treatment would be the alternate trode if only two treatments were performed). At the first visit, each patient was randomly assigned to a trode order protocol determined by rolling a standard six-sided die (Bicycle, The United States Playing Card Company, 2018), with each number corresponding to a specific protocol (Table 1). A single clinician (GJ) delivered all treatments and was blinded to which trode was being used. The trodes were grossly identical in emitted sound, appearance, and dimensions and labeled only on the part of the trode that plugged into the main unit (Figure 1). Trodes were plugged into the main unit by a veterinary technician, allowing for blinding of the observer.

At each treatment session, the patient was allowed to be positioned in either lateral recumbency, sitting or standing based on their comfort and where treatment was being applied. Minimal manual restraint was applied so that patients could easily move around in response to the trode. All patients were offered food (peanut butter, kibble, treats) while receiving treatment. Treatments were performed in the same space in the hospital to control for any behavioral response due to changes in the

FIGURE 1
The novel and standard shockwave trodes.

TABLE 2 Glasgow Composite Measure Pain Scale.

Patient behavioral signs	Assigned score	Treatment response
• Vocalization: Quiet • Response to trode/touch: No reaction • Posture/Activity: Quiet/comfortable	0	Go up in energy level
• Vocalization: Quiet • Response to trode/touch: Look at trode/around • Posture/Activity: Unsettled/restless	1	Stay at same energy level
• Vocalization: Crying/ whimpering, groaning • Response to trode/touch: Flinch, growl/guard • Posture/Activity: Hunched/tense	2	Go down in energy level
• Vocalization: Screaming • Response to trode/touch: Snap, cry • Posture/Activity: Rigid/Attempting to leave	3	Stop treatment

environment. Prior to treatment at each visit, the haircoat was evaluated and clipped if it exceeded 1/4".

Each patient was initially evaluated for noise reactivity by discharging ∼10 shocks both at a far distance (at least five feet away) and near distance (immediately adjacent to the patient). Noise reactivity was scored by the blinded clinician on a numerical 0–3 scale. A score of 0 indicated the patient did not react to the trode. A score of 1 was considered a mild reaction (i.e., the patient would look at the trode but could be easily distracted with food). A score of 2 was given if the patient had a moderate reaction (i.e., the patient would not take or stop taking food, body shaking, tucking tail, but did not try to actively get away). A score of 3 was given if the patient showed a severe reaction (i.e., actively tried to get away from the trode). Noise reactivity scores were recorded at each treatment with the higher score being recorded if near and far scores differed. Noise reactivity was tested and recorded at each session.

Consistent anatomic landmarks were used for treating patients to allow for a standardized treatment area. With each treatment, the center of the trode head was directed perpendicular to the intended tissue to receive treatment. For the shoulder, the protocol used by Leeman et al. was followed (11). For the hip, the treatment area was a circular region with a radius of 3 cm with the center of the greater trochanter marking the center of the treatment area. Both the hip and shoulder were treated from the lateral aspect only to maintain patient comfort during treatment. Treatment for the elbow was performed circumferentially with the treatment area measuring the distance from the lateral humeral epicondyle to olecranon caudally and centering the treatment at the level of the epicondyles. Stifles were treated in a U-shape along cranial, medial and lateral aspects of the joint with the center of the trode head pointing toward the middle of the imaginary cube created in the area between the fabella, patella, head of fibula, and tibial tuberosity.

The shockwave device (Zomedica PulseVet® ProPulse®. Ann Arbor, MI; trodes: ProPulse R05 and X-trode. Ann Arbor, MI) was programmed to deliver 1,000 shocks at a rate of 360 shocks/minute. Isopropyl alcohol and a coupling gel (LithoClear® Scanning Gel, Next Medical Products. Branchburg, NJ) was applied to the treatment area prior to initiation of treatment. Ear protection was not required to be worn by the clinicians and staff during treatment but were available for use if desired. Treatment was started and the patient's response was evaluated by the single blinded operator using a modified CMPS based on Reid et al. (26) (Table 2). Initial scoring was performed during the initial 200 shocks at an energy level of E2 with subsequent scoring approximately every 100 shocks after. Based on a patient's score, the energy level was either increased (score of 0), left the same (score of 1), decreased (score of 2), or treatment was stopped (score of 3). If a patient received a score of 2 at any point during treatment, the energy level was immediately decreased and reassessed within the next 100 shocks. If a patient received a score of 3, treatment was immediately discontinued. Treatment energy level was adjusted until a total of 1,000 shocks were delivered, or treatment was discontinued. After treatment, the patients were immediately discharged back to their owners.

A power calculation based on the tolerability of treatment energy was performed on preliminary data from 10 patients using Excel (Microsoft Corporation, Microsoft Excel. 2018. Redmond, WA). With a minimum detectable difference of two levels of energy and a significance level of 0.05, a desired sample size of 40 resulted in a power of 0.9919. The outcome measures were analyzed using a linear mixed model that was fit separately for each response variable (energy and number of shocks). Each individual dog was considered a random effect to account for the correlation among multiple repeated measures of the same subject. The type of trode, noise reactivity and joint treated were included in the model as fixed effects. The statistical analyses were performed using the R statistical software (R Core Team, R: lme4. 2022. Vienna, Austria). Residual diagnostic plots were used to evaluate model assumptions, and no obvious violations of modeling assumptions were identified. A $p < 0.05$ was used as a threshold for declaring statistical significance. Furthermore, the Holm procedure for multiple testing was considered for the two primary comparisons of energy and number of shocks (27, 28) to control the family-wise error rate at 0.05. The Holm procedure was implemented by first comparing the p-value for energy level ($p = 0.0007$) to 0.05/2, and then comparing the p-value for number of shocks ($p = 0.0384$) to 0.05. The comparisons were still significant under the Holm procedure and did not affect the conclusions. For all other comparisons and associations, no multiplicity adjustments were performed, and the p-values should be interpreted for descriptive purposes (29).

3. Results

Forty client-owned dogs with diagnosed pathology affecting the treated joints and/or associated soft tissues (stifles: $n = 9$, hips: $n = 9$, shoulders: $n = 11$, and elbows: $n = 11$) were enrolled in the study. None of the enrolled patients had undergone surgery of the affected joint within the 6 months prior to enrollment or had received any local anesthetic at the treatment site. The average age of the enrolled patient was 9.2 years (SD ± 3.95; range: 2–14.8) with most patients being sterilized (spayed: $n = 19$, neutered: $n = 17$, intact female: $n = 2$, intact male: $n = 2$). The most common breeds were Labrador Retrievers ($n = 11$), and mixed breed dogs ($n = 9$), followed by, American Pit Bull Terriers ($n = 2$), Border Collies ($n = 2$), German Shepherd Dogs ($n = 2$), and Golden Retrievers ($n = 2$). The remaining breeds included Greater Swiss Mountain Dog ($n = 1$), Rottweiler ($n = 1$), English Bulldog ($n = 1$), Australian Shepherd ($n = 1$), Bernese Mountain Dog ($n = 1$), Cane Corso ($n = 1$), French Bulldog ($n = 1$), Pembroke Welsh Corgi ($n = 1$), Mastiff ($n = 1$), Labradoodle ($n = 1$), and Vizsla ($n = 1$). Average patient weight was 29.7 kg (SD ± 8.08; range: 11–51.2 kg).

Thirty-three dogs completed all three treatment sessions, three dogs completed two sessions, and four dogs completed one session. Of the patients who did not complete the full treatment schedule, two were treated with both trodes, three with the novel trode alone and two with the standard trode alone. Reasons for participants to not complete the three scheduled treatment sessions included a lack of perceived patient improvement by the owners ($n = 5$), lost to follow up ($n = 1$), or euthanasia unrelated to the study ($n = 1$).

In total, treatment was initiated 53 times with the novel trode (average energy ± SD = 6.5 ± 2.5; average number of shocks administered ± SD = 848 ± 334) and 56 times with the standard trode (average energy ± SD = 5.3 ± 2.8; average number of shocks administered ± SD = 767 ± 358). When evaluating for tolerated energy level, there was evidence of improved tolerability with the novel trode after adjusting for noise reactivity and the joint treated ($p = 0.0007$). When further evaluating for noise reactivity and energy tolerability, there was evidence of correlation between the two ($p = 0.0168$): per unit of increased noise reactivity there was an estimated 0.69 unit (standard error: 0.284) lower tolerability of shockwave energy.

Similarly, when comparing number of shocks tolerated between the two trodes, there was evidence of improved tolerability with the novel trode after adjusting for noise reactivity and joint treated ($p = 0.0384$). There was also a positive correlation between noise reactivity and number of shocks, after adjusting for joint treated and treatment group ($p = 0.0097$): per unit of increased noise reactivity, patients tolerated an estimated 96.077 (standard error: 36.442) fewer shocks.

When comparing joints treated (comparison of all four groups together) using a one-way analysis of covariance (ANCOVA), there was no statistically significant difference in patients' tolerability of energy or number of shocks, after adjusting for treatment group and noise reactivity (energy: $p = 0.1012$; number of shocks: $p = 0.1641$). Pairwise comparison between the four joints (Tables 3, 4), however, suggested that hips had the highest tolerability and shoulders had the lowest tolerability. Since the pairwise comparisons were performed after a non-significant ANCOVA, the p-values associated with the contrasts presented in Tables 3, 4 should only be interpreted for descriptive purposes.

The only minor adverse event reported by a single owner was skin irritation after the initial treatment. The visit included clipping of the haircoat and resolved without treatment per the owner. No long-term adverse effects were reported by the clients or noted on veterinary examinations during the course of the study.

TABLE 3 Pairwise joint comparison for shockwave energy.

Contrast	Estimate	SE	p-value
Hip—Elbow	0.9	0.9	0.340
Shoulder—Elbow	−1.4	0.9	0.137
Shoulder—Hip	−2.2	0.9	0.015
Stifle—Elbow	−0.5	0.9	0.623
Stifle—Hip	−1.3	0.9	0.154
Stifle—Shoulder	0.9	0.9	0.320

TABLE 4 Pairwise joint comparison for number of shocks.

Contrast	Estimate	SE	p-value
Hip—Elbow	143.1	122.1	0.249
Shoulder—Elbow	−123.1	121.8	0.318
Shoulder—Hip	−266.2	119.2	0.032
Stifle—Elbow	69.6	126.5	0.586
Stifle—Hip	−73.5	124.4	0.558
Stifle—Shoulder	192.7	122.0	0.123

4. Discussion

Based on the results of the present study, awake shockwave therapy with a gradually increasing energy protocol is feasible in a selected group of patients with musculoskeletal disease affecting the shoulders, elbows, hips, and stifles. Furthermore, treatment using the novel trode is better tolerated both in terms of energy level reached and number of shocks delivered compared with the standard trode. Dogs in our study population, on average, were able to tolerate ∼1 level of higher energy and ∼80 additional shocks from the novel trode compared to the standard trode. Our study also showed a relationship between noise reactivity and awake shockwave tolerance, something that has not previously been reported. Further research is needed to evaluate if a gradually increasing energy treatment protocol is equally effective to a consistent energy level protocol. Additionally, further research is needed to evaluate the efficacy of the novel trode in comparison with a standard trode.

Although the data did not show a definitively higher tolerability for a single joint compared with the other three tested, it did suggest that the hips were the most highly tolerated joint. Possible explanations for this could be that the soft tissues surrounding the hips, namely muscle bellies, helped provide "padding" to the affected joint and surrounding major nerves. The remaining three joints (shoulders, elbows, knees) have less soft tissue coverage comparatively, which may result in more discomfort during treatment. Pairwise comparison also suggested lower tolerability for patients treated for shoulder pathologies. It is possible this was observed because the shoulders are physically closer to the patient's head and ears and the noise or physical presence of the trode near the head could have led to decreased tolerability. In addition, there was a higher prevalence of soft tissue pathology in the shoulder patient population, so it is possible that treatment of soft tissue pathologies with shockwave is more painful than degenerative joint disease. In a recent survey of members of the American Association of Equine Practitioners, the majority of respondents that used shockwave reported that "equine patients were moderately to completely tolerable of ESWT, regardless of the body region" (30). In human studies, the patients' tolerance can be a factor in the energy and/or number of shocks delivered during a treatment (1, 31). To the authors' knowledge, there have not been human studies evaluating tolerance of shockwave at different anatomic locations. Adverse effects reported in people for treatment of musculoskeletal disease include local pain, erythema, bruising, hematoma formation, nerve irritation, superficial edema, and even systemic signs including headaches and migraines (2, 32–35).

Shockwave therapy has been associated with minor adverse side effects in canines including pain during treatment, local bruising, ecchymosis and/or petechiation, hematoma formation and local swelling (3, 4, 36). Patients who were assigned higher modified Glasgow Composite Measure Pain Scale (CMPS) scores can be presumed to have had greater pain at the treatment area, consistent with reports in previous studies (4). The only other side effect noted during the study was skin irritation after the first treatment, but this was suspected to be related to coat clipping rather than the shockwave therapy itself as the irritation did not recur with subsequent treatments. Given the low incidence of adverse events, a comparison between the two trodes was not feasible.

The results of this study help support the use of shockwave for treating awake patients. While patients with musculoskeletal disease may be sedated for diagnostics or other routine outpatient procedures, it is not without its risks. Commonly used sedation medications include opioids and alpha-2 agonists, both of which have been shown to have negative cardiopulmonary effects on even healthy dogs (17–21). A survey of owners in the United States and Canada revealed that over 20% of owners strongly disagreed with the use of sedation during even routine exam (22).

The novel trode technology is described by the manufacturer as including a proprietary change to the reflector geometry designed to reduce the peak focal energy and spread the 5 MPa focal zone, which is considered the threshold for therapeutic effect of shock wave on tissue (24, 25, 37). This change is intended to reduce the pain of treatment while impacting a greater volume of tissue with the treatment. This approach, however, still differs from radial shockwave, which generates pressure waves that extend outwards equally from the generation source and lose energy at a rate proportional to radius^{-1}. This leads to lower amplitude waves that have a lower velocity, by two orders of magnitude, than the speed of sound in tissue (16).

There are several limitations to the present study, including the small sample size, particularly given that treatment was not limited to one specific joint. Another limitation was the subjective nature of the outcome measures. The authors attempted to decrease subjectivity through the use of a modified CMPS that has been validated in dogs for acute pain (38). While this judgment is subjective, to the authors' knowledge, there is no validated, objective method to determine acute pain that could be used in the study setting. To minimize bias and confounding factors, a single, blinded clinician performed all the scoring.

Because our study was focused on tolerability of treatment rather than clinical response, clinical metrology instruments or objective gait analysis were not used as outcome measures. Additional physiologic measures of stress or pain such as continuous blood pressure or heart rate monitoring were not used due to the potential to affect behavior response during collection and recording. Another potential limitation is that the patients' medical management protocols were not standardized due to the variety of conditions treated as well as severity. It is possible that patients who were receiving anti-inflammatory and/or analgesic medications may have shown higher tolerance to shockwave compared with patients not on these medications. Additionally, the severity of a patient's overall pain may have also affected their tolerance to therapy or noise sensitivity (39).

The inclusion criteria resulted in patients who were amenable to gentle restraint without the need for sedative or anxiolytic medications, which likely created bias toward patients with better tolerance. This also likely explains the high tolerability, even with the standard trode. The described exclusion criteria were chosen to help minimize additional confounding factors such as reactivity to restraint itself instead of the treatment or variations in serum plasma levels of medications due to differences in time of administration or dosing. As such, the results from this study cannot be extrapolated to more stressed patients. From a clinical perspective however, a patient who is not tolerating initial awake treatment could be given pre-visit oral anxiolytic medication at the next visit or the clinician could use earplugs in patients who appear noise reactive. Occupational Safety and Health Administration (OSHA) guidelines require ear protection for employees who are exposed to average noise levels above 85 decibels over an 8 h period (40). Per manufacturer recommendations, ear protection is recommended if sustained treatment is being performed. As our blinded clinician and staff were only exposed to shockwave treatment lasting no more than 4 min at a time and only a maximum of four treatments per day, ear protection was not required but available if desired. These recommendations should be considered by clinicians if longer treatments or multiple daily treatments are performed.

It was outside the scope of the study to compare the clinical efficacy of the novel trode to the standard trode when used with an electrohydraulic generator. Future blinded, prospective studies using objective outcomes are needed to determine if the novel trode provides different clinical outcomes compared with the standard trode. The gradually increasing energy protocol has also never been evaluated for clinical efficacy and additional prospective studies could be performed to evaluate whether its efficacy compared to a static, high energy treatment protocol.

The presented results support the use of ESWT in awake patients. The modified scale used in this study was originally developed to assess acute pain in patients, which is one of the primary limiting factors for treatment. The results show that while the novel trode was overall better tolerated than the standard trode, the standard trode still had better than anticipated tolerability, so either trode could be used to treat awake patients based on the clinician's discretion. It cannot be overstated that the purpose of this study was purely focused on tolerability of awake shockwave and should not be used to make conclusions regarding clinical efficacy of either trode or the protocol used.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The animal studies were approved by Institutional Animal Care and Use Committee and Clinical Review Board (IACUC: #1744 at Colorado State University). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the owners for the participation of their animals in this study. No potentially identifiable images or data are presented in this study.

Author contributions

GJ contributed to study design, data collection, and primary manuscript drafting. FD and LE contributed to study design and manuscript editing. TZ contributed to data analysis and manuscript editing. All authors contributed to the article and approved the submitted version.

Funding

Funding for the study was provided by William & Sandra Condon Family Foundation. The funding body played no role in the design of the study and collection, analysis, and interpretation of data and in writing the manuscript. Complimentary use of both standard and novel trodes was provided by Zomedica.

Acknowledgments

The authors would like to thank the Orthopedic Medicine and Mobility Clinical Trials team for their assistance with data collection.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2023.1249592/full#supplementary-material

References

1. Chung B, Wiley JP. Extracorporeal shockwave therapy: a review. *Sports Med.* (2002) 32:851–65. doi: 10.2165/00007256-200232130-00004

2. Reilly JM, Bluman E, Tenforde AS. Effect of shockwave treatment for management of upper and lower extremity musculoskeletal conditions: a narrative review. *PMR.* (2018) 10:1385–403. doi: 10.1016/j.pmrj.2018.05.007

3. Alvarez L. Extracorporeal shockwave therapy for musculoskeletal pathologies. *Vet Clin North Am Small Anim Pract.* (2022) 52:1033–42. doi: 10.1016/j.cvsm.2022.03.007

4. Dahlberg J, Fitch G, Evans RB, McClure SR, Conzemius M. The evaluation of extracorporeal shockwave therapy in naturally occurring osteoarthritis of the stifle joint in dogs. *Vet Comp Orthop Traumatol.* (2005) 18:147–52. doi: 10.1055/s-0038-1632954

5. Millis D, Drum M, Whitlock D. Complementary use of extracorporeal shock wave therapy on elbow osteoarthritis in dogs. *Vet Comp Orthop Traumatol.* (2011) 24:A1–10. doi: 10.1055/s-0037-1617481

6. Souza AN, Ferreira MP, Hagen SC, Patricio GC, Matera JM. Radial shock wave therapy in dogs with hip osteoarthritis. *Vet Comp Orthop Traumatol.* (2016) 29:108–14. doi: 10.3415/VCOT-15-01-0017

7. Mueller M, Bockstahler B, Skalicky M, Mlacnik E, Lorinson D. Effects of radial shockwave therapy on the limb function of dogs with hip osteoarthritis. *Vet Rec.* (2007) 160:762. doi: 10.1136/vr.160.22.762

8. Bockstahler B, Muller M, Skalicky M, Mlacnik E, Lorinson D. Extracorporeal radial shock wave therapy in dogs suffering from osteoarthritis of the elbow:

evaluation by measuring ground reaction forces. *Wien Tierarztl Monatsschr.* (2006) 93:39–46.

9. Danova NA, Muir P. Extracorporeal shock wave therapy for supraspinatus calcifying tendinopathy in two dogs. *Vet Rec.* (2003) 152:208–9. doi: 10.1136/vr.152.7.208

10. Venzin C, Ohlerth S, Koch D, Spreng D. Extracorporeal shockwave therapy in a dog with chronic bicipital tenosynovitis. *Schweizer ArchTierheilkd.* (2004) 146:136–41. doi: 10.1024/0036-7281.146.3.136

11. Leeman JJ, Shaw KK, Mison MB, Perry JA, Carr A, Shultz R. Extracorporeal shockwave therapy and therapeutic exercise for supraspinatus and biceps tendinopathies in 29 dogs. *Vet Rec.* (2016) 179:385. doi: 10.1136/vr.103487

12. Bockstahler B, Muller M, Hittmair KM. Extracorporeal radial shock wave therapy in dogs with tendinopathies: 3 case studies on a new treatment form. *Wien Tierarztl Monat.* (2007) 94:236–42.

13. Kieves NR, MacKay CS, Adducci K, Rao S, Goh C, Palmer RH, et al. High energy focused shock wave therapy accelerates bone healing. A blinded, prospective, randomized canine clinical trial. *Vet Comp Orthop Traumatol.* (2015) 28:425–32. doi: 10.3415/VCOT-15-05-0084

14. Barnes K, Faludi A, Takawira C, Aulakh K, Rademacher N, Liu C-C, et al. Extracorporeal shock wave therapy improves short-term limb use after canine tibial plateau leveling osteotomy. *Vet Surg.* (2019) 48:1382–90. doi: 10.1111/vsu.13320

15. van der Worp H, van den Akker-Scheek I, van Schie H, Zwerver J. ESWT for tendinopathy: technology and clinical implications. *Knee Surg Sports Traumatol Arthrosc.* (2013) 21:1451–8. doi: 10.1007/s00167-012-2009-3

16. McClure S, Dorfmüller C. Extracorporeal shock wave therapy: theory and equipment. *Clin Tech Equine Pract.* (2003) 2:348–57. doi: 10.1053/j.ctep.2004.04.008

17. Kellihan HB, Stepien RL, Hassen KM, Smith LJ. Sedative and echocardiographic effects of dexmedetomidine combined with butorphanol in healthy dogs. *J Vet Cardiol.* (2015) 17:282–92. doi: 10.1016/j.jvc.2015.08.008

18. Lee J, Suh S, Choi R, Hyun C. Cardiorespiratory and anesthetic effects produced by the combination of butorphanol, medetomidine and alfaxalone administered intramuscularly in Beagle dogs. *J Vet Med Sci.* (2016) 77:1677–80. doi: 10.1292/jvms.15-0065

19. Nishimura LT, Auckburally A, Santilli J, Vieira BHB, Garcia DO, Honsho CS, et al. Effects of dexmedetomidine combined with commonly administered opioids on clinical variables in dogs. *Am J Vet Res.* (2018) 79:267–75. doi: 10.2460/ajvr.79.3.267

20. Pan SY, Liu G, Lin JH, Jin YP. Efficacy and safety of dexmedetomidine premedication in balanced anesthesia: a systematic review and meta-analysis in dogs. *Animals.* (2021) 11:3254. doi: 10.3390/ani11113254

21. Sinclair MD. A review of the physiological effects of alpha2-agonists related to the clinical use of medetomidine in small animal practice. *Can Vet J.* (2003) 44:885–97.

22. Carroll AD, Cisneros A, Porter H, Moody C, Stellato AC. dog owner perceptions of veterinary handling techniques. *Animals.* (2022) 12:1387. doi: 10.3390/ani12111387

23. Barletta M, Raffe M. Behavioral response and cost comparison of manual versus pharmacologic restraint protocols in healthy dogs. *Can Vet J.* (2016) 57:258–64.

24. Wess O. Physics and technology of shock wave and pressure wave therapy. *In: 9th International Congress of the International Society for Musculoskeletal Shockwave Therapy (ISMST).* Rio de Janeiro: News Letter, ISMST (2006). p. 2–12.

25. Haecker A, Wess O. The role of focal size in extracorporeal shock wave lithotripsy. In: Loske AM, editor. *New Trends in Shock Wave Applications to Medicine and Biotechnology.* Kerala: Research Signpost (2010). p. 1–19.

26. Reid J, Nolan AM, Hughes JML, Lascelles D, Pawson P, Scott EM. Development of the short-form Glasgow Composite Measure Pain Scale (CMPS-SF) and derivation of an analgesic intervention score. *Anim Welf.* (2007) 16:97–104. doi: 10.1017/S096272860003178X

27. Holm S. A simple sequentially rejective multiple test procedure. *Scand J Stat.* (1979) 6:65–70.

28. Food and Drug Administration. *Multiple Endpoints in Clinical Trials: Guidance for Industry.* (2017). Available online at: https://www.fda.gov/regulatory-information/search-fda-guidance-documents/multiple-endpoints-clinical-trials-guidance-industry

29. Bender R, Lange S. Adjusting for multiple testing—when and how? *J Clin Epidemiol.* (2001) 54:343–9. doi: 10.1016/S0895-4356(00)00314-0

30. MacKay AV, McOnie RC, Riddell LP, Robinson KA. Characterization of the use of shock wave therapy among equine veterinarians. *Can Vet J.* (2020) 61:990.

31. Moya D, Ramon S, Schaden W, Wang CJ, Guiloff L, Cheng JH. The role of extracorporeal shockwave treatment in musculoskeletal disorders. *J Bone Joint Surg Am.* (2018) 100:251–63. doi: 10.2106/JBJS.17.00661

32. Tenforde AS, Borgstrom HE, DeLuca S, McCormack M, Singh M, Hoo JS, et al. Best practices for extracorporeal shockwave therapy in musculoskeletal medicine: clinical application and training consideration. *PMR.* (2022) 14:611. doi: 10.1002/pmrj.12790

33. Crevenna R, Mickel M, Schuhfried O, Gesslbauer C, Zdravkovic A, Keilani M. Focused extracorporeal shockwave therapy in physical medicine and rehabilitation. *Curr Phys Med Rehabil Rep.* (2021) 9:1–10. doi: 10.1007/s40141-020-00306-z

34. Testa G, Vescio A, Perez S, Consoli A, Costarella L, Sessa G, et al. Extracorporeal shockwave therapy treatment in upper limb diseases: a systematic review. *J Clin Med.* (2020) 9:453. doi: 10.3390/jcm9020453

35. Wang CJ. Extracorporeal shockwave therapy in musculoskeletal disorders. *J Orthop Surg Res.* (2012) 7:11. doi: 10.1186/1749-799X-7-11

36. Elster EA, Stojadinovic A, Forsberg J, Shawen S, Andersen RC, Schaden W. Extracorporeal shock wave therapy for nonunion of the tibia. *J Orthop Trauma.* (2010) 24:133–41. doi: 10.1097/BOT.0b013e3181b26470

37. Wess O, Ueberle F, Dührssen RN, Hilcken D, Krauss W, Reuner T, et al. *Working Group Technical Developments-Consensus Report.* Stuttgart: Thieme (1997).

38. Morton CM, Reid J, Scott EM, Holton LL, Nolan AM. Application of a scaling model to establish and validate an interval level pain scale for assessment of acute pain in dogs. *Am J Vet Res.* (2005) 66:2154–66. doi: 10.2460/ajvr.2005.66.2154

39. Lopes Fagundes AL, Hewison L, McPeake KJ, Zulch H, Mills DS. Noise sensitivities in dogs: an exploration of signs in dogs with and without musculoskeletal pain using qualitative content analysis. *Front Vet Sci.* (2018) 5:17. doi: 10.3389/fvets.2018.00017

40. Occupational Safety and Health Administration. *Occupational Noise Exposure.* Washington, DC: United States Department of Labor (2011).

TYPE Original Research
PUBLISHED 08 January 2024
DOI 10.3389/fvets.2023.1258319

Check for updates

OPEN ACCESS

EDITED BY
David Levine,
University of Tennessee at Chattanooga,
United States

REVIEWED BY
Bess Pierce,
University of Missouri, United States
Sarah Love,
Sport Dog Specialty Medicine, United States

*CORRESPONDENCE
Frank C. Tsai
✉ frank.tsai@amcny.org

RECEIVED 13 July 2023
ACCEPTED 13 December 2023
PUBLISHED 08 January 2024

CITATION
Tsai FC and Alvarez LX (2024) Outcome of eight working dogs with fibrotic myopathy following extracorporeal shockwave and rehabilitation therapy: a case series. *Front. Vet. Sci.* 10:1258319. doi: 10.3389/fvets.2023.1258319

Outcome of eight working dogs with fibrotic myopathy following extracorporeal shockwave and rehabilitation therapy: a case series

Frank C. Tsai* and Leilani X. Alvarez

Department of Integrative and Rehabilitative Medicine, Schwarzman Animal Medical Center, New York, NY, United States

Introduction: Fibrotic myopathy of the gracilis, semitendinosus, and semimembranosus is described primarily in working German Shepherd dogs. The purpose of this case series is to describe the rehabilitation modalities and treatments utilized in working dogs with fibrotic myopathy and the time frame they were able to continue working.

Methods: Medical records of patients with hindlimb lameness that were presented to the Schwarzman Animal Medical Center in New York City from 2012 to 2023 were retrospectively searched. Signalment, history, clinical evaluation, gait analysis, goniometry of stifles, and follow-up evaluation were compared among patients. Ten male working dogs met inclusion criteria. Extracorporeal Shockwave Therapy (ECSWT) was administered under sedation or general anesthesia. Rehabilitation therapy (RT), including massage, hamstring stretch, photobiomodulation, pulsed electromagnetic field therapy, warm compress, therapeutic ultrasound, underwater treadmill, and therapeutic exercises, were performed once every one to 3 weeks with varying protocols according to patient assessments. Follow-up phone calls and emails were conducted to determine long-term outcome.

Results: On average, dogs were able to work full-time for 32.1 months (range 6–82; SD 23.6) from the time of diagnosis. No activity limitation was reported by the owners/handlers.

Discussion: This report is the first to describe non-invasive medical treatments that may extend the working ability of dogs diagnosed with fibrotic myopathy. Further prospective randomized controlled studies are needed to demonstrate the efficacy of ECSWT and RT for treating fibrotic myopathy.

Conclusion: The results of this retrospective study suggest that the combination of ECSWT and RT may allow working dogs with fibrotic myopathy to continue their working capacity for an extended period of time.

KEYWORDS

fibrotic myopathy, extracorporeal shockwave therapy, gracilis, semitendinosus, German shepherd, working dogs, muscle contracture

Introduction

Fibrotic myopathy, specifically of the gracilis, semitendinosus, or semimembranosus, is an uncommon disease in dogs. It has been reported in the German shepherd, Belgian Malinois, Doberman Pinscher, Rottweiler, and Old English Sheepdog (1–6). Predominantly young adult, male German shepherd working dogs, or dogs with active lifestyles, are reported (1, 5). The exact etiology is still unknown but various causes are proposed. Muscle trauma, either from repeated muscle strains or a single event is likely the primary cause (1, 2, 4). Other explanations include compartment syndrome, fractures, infection (Neospora), immune-mediated, neuropathy, and immobilization (7). Regardless of the original insult, disease progression is usually associated with breakdown of muscle fibers and replacement by fibrous tissue and subsequent muscle contracture and loss of elasticity (5, 6).

Typically, acute trauma/injury is not reported by the owners/handlers in most cases (4, 5). Gait abnormality is usually the only symptom reported with no associated pain and can sometimes be mistaken as neurological disease. Except for acute muscle strain injury, improvement usually is not observed with pain medications (including non-steroidal anti-inflammatory drugs, opioids, etc.), or rest (4, 8).

Although trauma, whether a single event or repeated microtrauma, has been suspected to be the cause of fibrotic myopathy of gracilis/semitendinosus in dogs, etiopathogenesis remains elusive. Adding to the complexity, in racing Greyhounds, rupture of the gracilis muscle results in some degree of contracture and adhesion, but the gait is not affected (1), suggesting a genetic predisposition of German Shepherds and Malinois breeds. Fibrotic myopathy of the gracilis, semimembranosus, and/or semitendinosus muscles causes a distinctive gait pattern—with a shortened stride, rapid elastic medial rotation of the paw, external rotation of the hock, and internal rotation of the stifle during mid- to late-swing phase of the stride (3–5, 9). The lameness might be more noticeable at a trot. On physical examination, a taut band can be palpated, depending on which muscle is affected. Pain may or may not be noticed on muscle palpation. Joint range of motion is expected to be decreased during hip abduction, stifle extension, and tarsal extension (4, 9).

Medical and surgical management has been described with guarded prognosis (3–5). Medical management, including therapeutic ultrasound, immunosuppressive dose of corticosteroids, D-Penicillamine and colchicine did not improve the condition (3, 4). Post-surgery rehabilitation therapy, including cross-fiber friction massage, passive joint range of motion, and controlled exercises did not yield sustained improvement either (3, 10). Previous reports of surgical interventions resulted in immediate improvement, if not full resolution of the lameness, but the lameness was expected to recur in 2–4 months (1, 4, 5).

In one study (8), authors demonstrated that adipose-derived mesenchymal stem cells could improve or help prevent progression of fibrosis and muscle contracture in dogs with semitendinosus myopathy. It is worth noting the cases were treated early and only 3/10 cases had evidence of scar (fibrous) tissue formation (true fibrotic myopathy).

Extracorporeal Shockwave Therapy (ECSWT) has been used to treat various musculoskeletal conditions, including bone healing, tendinopathy, patellar desmopathy, acute/subacute myopathies, lumbosacral disease/pain, and osteoarthritis (11). It has been documented that ECSWT could noninvasively, effectively, and safely prevent the formation of arthrofibrosis during knee repair in rabbits (12).

In one human study, ECSWT was comparable to intralesional steroid injection for treatment of keloid scars (13). A systematic review for the safety and efficacy of treating post-burn scars suggests that the combination of ECSWT and comprehensive rehabilitation therapy (RT) had better therapeutic effect on post-burn pathological scars than RT alone, without obvious side effects (14). ECSWT has been used with variable success to treat fibromatosis diseases in people, including plantar (Ledderhose disease), palmar (Dupuytren's disease), and penile fibromatosis (Peyronie's disease) (15–18).

Although dogs can remain active in spite of the pathognomonic gait/lameness (1), the muscle contracture from fibrosis can be career-ending for working police dogs (8). To date, the effect of ECSWT on fibrotic myopathy in working dogs, and specifically, the ability to continue to work, has not been described.

The aim of this case series was to document the treatment and outcomes of ECSWT and RT on working dogs with hindlimb fibrotic myopathy, and to report the length of time they were able to continue working full-time after diagnosis.

Our hypothesis was that ECSWT and RT would enable working dogs with hindlimb fibrotic myopathy to continue working full-time after the time of diagnosis for an average of 1 year (12 months) or longer.

Materials and methods

Medical records of canine patients with a chief complaint of hind limb lameness presented to the Schwarzman Animal Medical Center (AMC) in New York City between January 2012 to June 2023 were retrospectively searched in the electronic medical record database and evaluated. The terms, "fibrotic myopathy" and "canine" were searched. Exclusion criteria included pet dogs (non-working), forelimb fibrotic myopathy, or a diagnosis that was not conclusive or after retirement. Signalment, history, clinical evaluation, thigh girth measurement, gait analysis (both subjective and objective if available), goniometry of stifles, and follow-up evaluation were compared. All ECSWT was performed with the same electrohydraulic machine (VersaTron, PulseVet, Alpharetta, GA, United States). The setting for the ECSWT was: 1,000 pulses at energy level E6 (0.15 mJ/mm^2; however, energy densities are not comparable across different ECSWT devices) (11) to each affected muscle using 20 mm trode. Treatments were administered under sedation every 2 weeks for a total of 1–3 treatments.

Thigh girth measurements were performed using a Gulick II tape measure (Country Technology, Inc. Gays Mills, WI, United States). It was measured in a consistent manner over the greater trochanter in standing posture. Subjective lameness was graded as none (I), mild (II), moderate (III), or severe (IV) (19). Objective gait analysis was conducted using a pressure-sensitive walkway system (Gait4Dog, CIR Systems, Franklin, NJ, United States) with a minimum of three consistent gait passes.

All patients had either musculoskeletal ultrasound (MSK US) examination performed by a board-certified radiologist, magnetic resonance imaging (MRI; reviewed by a board-certified

TABLE 1 Patient demographics.

Patient	1	2	3	4	5	6	7	8	Mean SD	9	10	Mean SD	Total mean SD
Age (years) at the time of diagnosis	6	6	5.5	2.5	6.25	5.4	3.8	4.75	5.0 1.2	5	9.83	7.4 2.4	5.5 1.8
Breed	GSD	GSD	GSD	GSD	GSD	GSD	GSD	Mal		Shep	GSD		
Neuter status	N	N	N	N	I	I	N	N		I	I		
Job description	PD	PD	PD	GD	PD	PD	PD	PD		PD	PD		
Muscles affected	G, SM, B	G, B	G, B	G, SM, L	G, SM, L	G or SM, B	SM, B	G, B		G, SM, B	ST, B		

All were male dogs. GSD, German shepherd dog; Mal, Belgian Malinois; Shep, Shepherd—not specified; N, Neutered; I, Intact; PD, Police Dog; GD, Guide Dog for the Blinds; G, Gracilis Muscle; SM, Semimembranosus Muscle; ST, Semitendinosus Muscle; B, Bilateral; R, Right; L, Left.

radiologist), or clinical evaluation by a board-certified specialist in either sport medicine and rehabilitation, surgery, or neurology. The criteria for diagnosis of gracilis/semitendinosus/semimembranosus fibrotic myopathy included firm taut bands on palpation of the caudomedial thigh, identifying the origin/insertion of the fibrotic muscles, and the pathognomonic gait (as described previously). Additionally, the degree of hamstrings flexibility was noted.

The patients were sedated prior to the administration of ECSWT, except two patients (one was performed under general anesthesia; Midazolam 0.5 mg/kg IV, Propofol 3 mg/kg IV, Isoflurane and the other was performed non-sedated), under a protocol chosen by the supervising clinician (Nalbuphine 0.2 mg/kg IV/IM + Midazolam 0.2 mg/kg IV/IM+ Propofol 2.4–3.5 mg/kg IV; Nalbuphine 0.2 mg/kg IV/IM+ Dexmedetomidine 7–10 mcg/kg IV/IM; Dexmedetomidine 5–7 mcg/kg IV/IM + Hydromorphone 0.1 mg/kg IV or Methadone 0.1 mg/kg IV + Dexmedetomidine 6 mcg/kg IV).

Rehabilitation therapy included manual therapies (massage, passive joint range of motion of the hip, stifle joints, stretching of the gracilis/semimembranosus/semitendinosus), photobiomodulation to hamstrings (Machine 1: Pain and Trauma setting, 10 W, 2,600–3,120 joules total, ~7–9 J/cm^2, Companion, LiteCure LLC, Newark, DE, United States; Machine 2: Wound healing setting, 101–151 joules total, 2 J/cm^2, MLS, Mphi VET, ASALASER, Arcugnano, Italy), Pulsed Electromagnetic Field (PEMF) therapy (15 min over hamstrings; Assisi loop, Assisi Animal Health, Santa Fe, NM, United States), warm compress (10–15 min over hamstrings before massage and stretching), customized therapeutic exercises and underwater treadmill walking, individualized according to patient assessment. Typically, RT lasted about 50–60 min and was performed once weekly.

Therapeutic ultrasound (Chattanooga, DJO LLC, Vista, CA, United States) was used over affected muscles (5 cm^2 head, 1.0 MHz, 50–100%, 0.5–1 W/cm^2 for 7–10 min) in some patients after the course of ECSWT. Duty cycle was chosen for non-thermal (50%) and thermal effects (100%).

Each patient had follow-up evaluations with the rehabilitation therapists/specialists or primary care veterinarians. Outcome measurements were performed by either a Diplomate of the American College of Veterinary Sports Medicine and Rehabilitation (DACVSMR), a certified rehabilitation veterinarian or technician, or internship-trained primary care veterinarian at the AMC. Follow-up phone calls/emails were conducted by the primary author. Patients were followed-up either by in-person examination or via phone call to report the status of working ability.

Results

A total of 17 cases were identified in the medical record system who had a diagnosis of gracilis/semimembranosus/semitendinosus fibrotic myopathy. Five non-working dogs were excluded. Two additional working dogs were excluded because the diagnosis of fibrotic myopathy was after retirement. Out of the 10 cases included in this case series, there were nine police dogs, and one guide dog.

All cases evaluated were male German shepherd dogs, except one male Belgian Malinois with ages ranging from 2.5 to 9.8 years old at the time of diagnosis (mean 5.5 SD 1.8) (Table 1). Six were castrated and 4 were intact (Table 1). The ages of 8 patients who received ECSWT and RT (treatment group) ranged from 2.5 to 6.3 years old (mean 5.0 SD 1.2) (Table 1). Two patients who did not receive ECSWT or RT were 5 and 9.8 years old at the time of diagnosis (mean 7.4 SD 2.4) (Table 1).

No specific activities or events were identified by the owners/handlers that led to the unusual gait.

Three of the 8 patients in the treatment group had MRI to confirm the diagnosis of fibrotic myopathy of gracilis or semimembranosus. One patient had MSK US to confirm the diagnosis of fibrotic myopathy. The rest of the patients were diagnosed based on palpation of fibrotic bands and pathognomonic gait. One of the two patients who did not receive ECSWT or RT (non-treatment group) was diagnosed with fibrotic myopathy before his retirement per the handler 2 years prior to presentation. No referral record could be obtained (the previous clinic was closed and bought by another practice that did not keep his complete medical record) to verify the diagnosis. The diagnosis of fibrotic myopathy was confirmed by a board-certified surgeon at the AMC (2 years after his retirement and 4 years after diagnosis, through palpation and pathognomonic gait).

All 8 patients of the treatment group received ECSWT. Six of the patients had the recommended 3 treatments spaced 2 weeks apart and 2 had just one treatment. All 8 patients also received customized therapeutic exercises and manual therapies (Table 2). Other therapeutic rehabilitation therapies administered to the dogs are outlined in Table 2.

For the 2 patients in the non-treatment group, no objective outcomes were available because they did not return for follow-up with reference to the fibrotic myopathy diagnosis or treatment.

Regarding the treatment outcomes, 2 out of the 8 patients were noted to have a softer muscle belly of the affected muscles after treatment with ECSWT. Others did not have noticeable change.

Stifle range of motion (ROM) improved or stayed within the normal range in 5 patients within 7 months from the initial

TABLE 2 Rehabilitation treatments performed in dogs with fibrotic myopathy.

Patient treatment	1	2	3	4	5	6	7	8	9	10
ECSWT (# of treatments)	+ (3)	+ (3)	+ (3)	+ (1)	+ (3)	+ (1)	+ (3)	+ (3)	0	0
Muscles treated by ECSWT	G, SM, B	G, B	G, B	G, SM, L	G, SM, B	G-B, SM- R	G, SM, B	G, L	–	–
Manual therapy (passive joint range of motion, hamstring stretching, massage)	+	+	+	+	+	+	+	+	None	None
Photobiomodulation	+	+	+	+	+	–	–	–	–	–
Superficial heat	+	+	–	–	–	–	+	–	–	–
Therapeutic ultrasound	+	+	–	+	+	+	+	+	–	–
PEMF	–	–	–	–	+	+	–	–	–	–
Underwater treadmill	+	+	+	+	–	+	+	+	–	–
Land treadmill	–	–	–	–	+	–	–	–	–	–
Therapeutic exercises	+	+	+	+	+	+	+	+	–	–
RT Frequency (every_weeks)	1–3	1–3	1–2	1–2	1–2	1	1	1	–	–
RT total # of treatments	10	77	4	392	18	3	9	18	–	–

+, performed; –, not performed; ECSWT, Extracorporeal Shockwave Therapy; PEMF, Pulsed Electromagnetic Field; RT, Rehabilitation Therapy; G, Gracilis Muscle; SM, Semimembranosus Muscle; ST, Semitendinosus Muscle; B, Bilateral; R, Right; L, Left.

measurements. One dog had decreased stifle extension within 7 months (Table 3). The other 2 patients did not have objective ROM measurements during initial evaluation or follow-up. One dog in the treatment group maintained improved stifle extension 18 months after the initial measurement (Table 3).

Three out of the 4 patients who were measured had improved or maintained thigh girth within 4.5 months from the initial measurements. Out of those 3, one had regressed slightly at the 19-month recheck. The other patient initially declined in the thigh girth, and then improved (Table 3).

Three dogs had improved subjective lameness evaluation (less kyphotic stance, or decreased lameness grade from II/IV to I/IV, or less pronounced pathognomonic gait). The other 5 dogs did not have specified gait/lameness change (Table 3).

On average, dogs who received ECSWT and RT were able to work full-time for an additional 32.1 months after the diagnosis of fibrotic myopathy (range 6–82; SD 23.6) (Table 3). Dog #8 was not included in this calculation because he is still actively working at full capacity (13 months since time of diagnosis).

On average, dogs who did not receive ECSWT or RT were able to work full-time for an additional 12.5 months (range 1–24; SD 11.5).

One of the 2 dogs in the non-treatment group was able to work full-time for 24 months with limitations (could not jump in and out of a car or climb stairs). The other dog retired soon after the diagnosis (within 1 month) because he was not able to jump into the patrol vehicle and this disqualified him from being able to work.

No activity limitation was reported for patients who received ECSWT and RT, except that one handler limited jumping due to concern for making the contralateral leg worse. Working duties of the dogs included explosive detection, patrol, and guiding for the blind.

The follow-up for this retrospective study was completed by either phone call or email, 9 months to 7 years after the last treatment. For the non-treatment group, follow-up for one was 2.5 years and the other 10 months after the last evaluation.

Study patients had other comorbidities listed in the medical record including intervertebral disk disease, osteoarthritis, hip pain, iliopsoas pain, tail pain, and hemangiosarcoma. Since we could not obtain the official deposition record, we could not confirm the exact reason for each dog's retirement.

Discussion

The results of this retrospective study on 10 working dogs with hindlimb fibrotic myopathy suggested that the combination of ECSWT and RT may allow dogs to continue their working capacity for an average of 32.1 mo (range 6–82; SD 23.6) from the time of diagnosis, thereby confirming our hypothesis. We were not able to statistically compare outcomes with the non-treatment group due to low sample size (2 patients); however, dogs receiving ECSWT and RT in this retrospective series were able to work on average 19.6 mo longer (SD 26.3) as compared to the non-treatment group. While several other modalities were performed, ECSWT was the only consistent modality that all dogs received, in addition to therapeutic exercises and manual therapy (Table 2). This report is the first to describe non-invasive medical treatments that may extend the working ability of dogs diagnosed with fibrotic myopathy of gracilis, semimembranosus, and/or semitendinosus.

Theories regarding the mechanisms of ECSWT to aid in healing of fibrotic myopathy are variable. In terms of human plantar fibromatosis, it is thought that ECSWT stimulates biosynthesis of the extracellular matrix by tendon fibroblasts, which could help in counteracting the maturation process of myofibroblasts and lead to reduced tissue contraction (18). Other theories include that ECSWT causes direct damage to the lesion triggering a healing response, and ECSWT increases vascularity to the lesion, lysing the lesion and resulting in macrophage removal (20). Studies have also demonstrated that ECSWT may inhibit transforming growth factor-β1 (TGF-β1), which plays an important role in enhancing muscle fibrosis (21–24).

Pain reduction by the ECSWT has also been documented in people with fibromatosis diseases (15, 17, 18). Even though fibrotic myopathy usually does not elicit lameness secondary to pain, it can cause pain when the muscle/tendon is stretched above the physiological range. While it was not reported in the patients of this

TABLE 3 Summary of treatment outcomes after extracorporeal shockwave therapy and rehabilitation therapy in dogs with fibrotic myopathy.

Patient outcome	1			2			3			4		
	Time (mo)	L	R	Time (mo)	L	R	Time (mo)	L	R	Time (mo)	L	R
Passive stifle extension (degrees)	0 7	160 135	160 135	0 8	143 147	119 120	0 7 10 12 18	119 162 155 157 157	111 135 144 147 150	5 34 46 79 81	166 165 160 153 153	165 165 160 150 148
Thigh girth (cm)	0 4.5	50.9 58	50.2 57.5	0 8	55 55.2			–		0 21 46 79 81	55 53 53 53.2 55.6	
Visual lameness evaluation (grade I-IV)	5	Less kyphotic		0 18	II I			No change			–	
Time from initial diagnosis to retirement (mo)		9			27			41			82	

Patient outcome	5			6			7	8			9	10
	Time (mo)	L	R	Time (mo)	L	R		Time (mo)	L	R		
Passive stifle extension (degrees)	0 7 9	164 163 142	163 162 156	0.5 Pre-ECSWT Post-ECSWT		123 147	–	0 3 11	123 155 150	128 150 155	–	–
Thigh girth (cm)	0 7 19	42.6 43 42.3			–		–		–		–	–
Visual lameness evaluation (grade I-IV)		–			No change		No change	3 5	Pathognomonic gait less pronounced No change		–	–
Time from initial diagnosis to retirement (mo)		24			6		36		*13		24	1

*Still working full-time at the time of publication. ↑, Improved; ↓, Regressed; –, Not Available; L, Left; R, Right; mo, months.

study, in one report (4), most dogs showed pain responses with digital pressure exerted on the affected muscle(s), abduction of the coxofemoral joint(s), or both.

In addition to ECSWT, manual therapy, including massage, passive joint range of motion, and stretching can help collagen/scar tissue to align properly and decrease pain, and is important to help increase flexibility and improve muscle extensibility (25). Therapeutic exercises, focusing on active joint range of motion, warm-up, stretching, and muscle strengthening can also help increase flexibility and prevent future muscle strain. The outcome of the patients presented here likely benefited from these rehabilitation strategies.

Historically, clients/handlers have been told that working dogs' careers are over when they are diagnosed with fibrotic myopathy. Through client education, they understand that their dogs can continue to work without pain and/or causing additional harm. Additionally, the instruction for activity modification and home exercise program might delay worsening of the contracture and improve functional mobility through required tasks.

Objective gait evaluations using the pressure-sensitive walkway system were only conducted in patients #3 and #4. Inconsistent variations of results were recorded, likely due to the nature of mechanical lameness with fibrotic myopathy. Therefore, this data was not included. Other treatment outcomes, including muscle texture, stifle extension, thigh girth, and subjective lameness exam, did not yield consistent positive results. Those measurements did not correlate with extending the working lifespan of each dog either.

In this retrospective study, we did not assign the severity of the fibrotic myopathy as there is currently no published grading system available, either in clinical examination, or diagnostic imaging modalities (MRI, MSK US), or histopathological evaluation. Despite inconsistent phenotypic improvement, future studies might evaluate the change in fiber pattern with serial MRI or MSK US of the affected muscles to elucidate the effects of ECSWT and RT on canine fibrotic myopathy.

Human studies have used MSK US to evaluate the outcomes of musculoskeletal conditions following ECSWT (18, 26). In one study regarding plantar fibromatosis, the researchers did not find significant changes in length and width of fibroma with sonogram. Reduction in the thickness of the lesion and long-term benefit in pain relief and functional outcomes were noted though (18). In future veterinary studies, the addition of MSK US to follow changes in contracture fibrosis size or progression is recommended.

Working dogs, including military working dogs (MWDs), other federally owned working dogs, police working dogs, and service/guide dogs, provide crucial functions in national defense, public safety, and personal assistance. Maximizing longevity of their service is not just important for the handlers/owners, but also critical for the financial viability of the institutions. The cost of dog acquisition/training before entering active service ranges from $15,454 to $85,000 (27–29). In a study by Moore et al. (30), mean age at death for MWDs in active service was 10 years. The working life of the guide dog is estimated to be 8 years (28). Since fibrotic myopathy is a disease of young adult dogs, increasing the workability of working dogs by an average of 32.1 months with the ECSWT and RT is a significant benefit for the institutions and the handlers.

Limitations of this study are primarily related to the retrospective nature of this case series report including incomplete and inconsistent objective evaluations, and inconsistent rehabilitation treatments that make meaningful comparisons challenging. Recall bias from the owners/handlers could also influence the conclusion because the time and causes of retirement could not be independently verified without the official disposition records, as they are proprietary information. Another limitation is the small number of patients that may not represent the true demographics of the working dog population (male dogs may simply be over-represented in this study), as well as outcomes that may not be repeatable or be different at another rehabilitation facility. A prospective study should be considered in the future, especially evaluation of ECSWT as a potential definitive treatment option for fibrotic myopathy.

Additionally, the absence of an appropriate control group (both in terms of patient numbers and objective outcome measures) is another significant limitation. The low incidence of the disease (or lack of recognition) and lack of standards on assessing workability in working dogs, contributes to the inability of designating an appropriate control group that may conclusively support the use of ECSWT and RT.

While our outcome measures did not demonstrate consistent improvement among the patients, to the authors' knowledge, there is no standardized functional assessment for police or MWDs with various jobs, including explosive detection and patrol. In particular, we have no objective outcome measures that can assess or predict when a working dog can return to full function and work duties following injury. Recent work by Farr et al. at the Penn Vet Working Dog Center in 2020, provides assessment of a working dog's foundational fitness (31). Additional studies and refinement will help to provide better assessment as to whether a working dog can continue to work in different functions, given they have different demands in different jobs. Currently, the return-to-work assessment is determined by the veterinarian, handler, and immediate supervisor (or kennel master).

In conclusion, this retrospective case series may support the use of ECSWT and RT for maintaining working capacity of dogs after diagnosis of hindlimb fibrotic myopathy; however, further studies are needed before definitive treatment recommendations can be made.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements. Ethical approval was not required for the studies involving animals in accordance with the local legislation and institutional requirements because of the retrospective nature of the study: handlers have consented to have their working dogs included in the study. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

FT: Data Curation, Writing – original draft, Writing – review & editing. LA: Conceptualization, Formal Analysis, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Vaughan LC. Muscle and tendon injuries in dogs. *J Small Anim Pract*. (1979) 20:711–36. doi: 10.1111/j.1748-5827.1979.tb06688.x

2. Clarke RE. Fibrosis and contracture of the semitendinosus muscle in a dog. *Aust Vet J*. (1989) 66:259–61. doi: 10.1111/j.1751-0813.1989.tb13585.x

3. Steiss JE. Muscle disorders and rehabilitation in canine athletes. *Vet Clin N Am Small Anim Pract*. (2002) 32:267–85. doi: 10.1016/S0195-5616(03)00088-3

4. Lewis DD, Shelton GD, Piras A, Dee JF, Robins GM, Herron AJ, et al. Gracilis or semitendinosus myopathy in 18 dogs. *J Am Anim Hosp Assoc*. (1997) 33:177–88. doi: 10.5326/15473317-33-2-177

5. Moore RW, Rouse GP, Piermattei DL, Ferguson HR. Fibrotic myopathy of the semitendinosus muscle in four dogs. *Vet Surg*. (1981) 10:169–74. doi: 10.1111/j.1532-950X.1981.tb00654.x

6. Taylor J, Tangner CH. Acquired muscle contractures in the dog and cat. A review of the literature and case report. *Vet Comp Orthop Traumatol*. (2007) 20:79–85. doi: 10.1160/VCOT-06-01-0007

7. Carmichael S, Marshall WG. "Muscle and tendon disorders", In: Johnston SA, Tobias KM, editors. *Veterinary surgery: Small Animal Expert Consult*. St. Louis, MO: Elsevier (2018). p. 1316–1322.

8. Gibson MA, Brown SG, Brown NO. Semitendinosus myopathy and treatment with adipose-derived stem cells in working German shepherd police dogs. *Can Vet J*. (2017) 58:241–6.

9. Hayashi K, Schulz KS. "Management of muscle and tendon injury or disease." In: Fossum TW, editor. *Small Animal Surgery*. Philadelphia, PA: Elsevier (2019). p. 1280–1294.

10. Steiss JE, Levine D. Physical agent modalities. *Vet Clin North Am Small Anim Pract*. (2005) 35:1317–33. doi: 10.1016/j.cvsm.2005.08.001

11. Alvarez L. Extracorporeal shockwave therapy for musculoskeletal pathologies. *Vet Clin North Am Small Anim Pract*. (2022) 52:1033–42. doi: 10.1016/j.cvsm.2022.03.007

12. Zhou Y, Yang K. Prevention of arthrofibrosis during knee repair by extracorporeal shock wave therapy: preliminary study in rabbits. *Injury*. (2019) 50:633–8. doi: 10.1016/j.injury.2019.01.054

13. Wang C, Ko J, Chou W, Cheng J, Kuo Y. Extracorporeal shockwave therapy for treatment of keloid scars. *Wound Repair Regen*. (2018) 26:69–76. doi: 10.1111/wrr.12610

14. Yang Y, Kang J, Jiang T, Schmitz C, Weng C, Zhang L. Safety and efficacy of treating post-burn pathological scars with extracorporeal shock wave therapy: a meta-analysis of randomized controlled trials. *Wound Repair Regen*. (2022) 30:595–607. doi: 10.1111/wrr.13037

15. Knobloch K, Vogt PM. High-energy focused extracorporeal shockwave therapy reduces pain in plantar fibromatosis (Ledderhose's disease). *BMC Res Notes*. (2012) 5:542. doi: 10.1186/1756-0500-5-542

16. Aykut S, Aydin C, Ozturk K, Arslanoglu F, Kilinc CY. Extracorporeal shock wave therapy in Dupuytren's disease. *Sisli Etfal Hastan Tip Bul*. (2017) 52:124–8. doi: 10.5350/SEMB.20171109074840

17. Abdulsalam AJ, Shehab D, Elhady AA, Abraham M. High-energy focused extracorporeal shockwave therapy relieved pain in Dupuytren's disease: a series of seven hands. *Eur J Phys Rehabil Med*. (2018) 55:862–4. doi: 10.23736/S1973-9087.18.05498-9

18. Hwang JT, Yoon KJ, Park C, Choi JH, Park H, Park YS, et al. Follow-up of clinical and sonographic features after extracorporeal shock wave therapy in painful plantar fibromatosis. *PLoS One*. (2020) 15:e0237447. doi: 10.1371/journal.pone.0237447

19. Greene LM, Marcellin-Little DJ, Lascelles DX. Associations among exercise duration, lameness severity, and hip joint range of motion in Labrador retrievers with hip dysplasia. *J Am Vet Med Assoc*. (2013) 242:1528–33. doi: 10.2460/javma.242.11.1528

20. Carroll P, Henshaw RM, Garwood C, Raspovic K, Kumar D. Plantar fibromatosis pathophysiology, surgical and nonsurgical therapies – an evidence-based review. *Foot Ankle Spec*. (2018) 11:168–76. doi: 10.1177/1938640017751184

21. Huang P, Zhang Q, Zhou Y, Liu A, Wang F, Xu Q, et al. Effect of radial extracorporeal shock wave combined with ultrashort wave diathermy on fibrosis and contracture of muscle. *Am J Phys Med Rehabil*. (2021) 100:643–50. doi: 10.1097/PHM.0000000000001599

22. Walton K, Johnson K, Harrison C. Targeting TGF-β mediated SMAD signaling for the prevention of fibrosis. *Front Pharmacol*. (2017) 8:461. doi: 10.3389/fphar.2017.00461

23. Mahdy M. Skeletal muscle fibrosis: an overview. *Cell Tissue Res*. (2019) 375:575–88. doi: 10.1007/s00441-018-2955-2

24. Cui H, Hong A, Kim J, Yu J, Cho Y, Joo S, et al. Extracorporeal shock wave therapy alters the expression of fibrosis-related molecules in fibroblast derived from human hypertrophic scar. *Int J Mol Sci*. (2018) 19:124. doi: 10.3390/ijms19010124

25. Millis D, Levine D. "Range-of-motion and stretching exercises." In: Millis DL, Levine D, editors. *Canine Rehabilitation and Physical Therapy*. Philadelphia, PA: Elsevier (2014). p. 431–446.

26. Al-Abbad H, Allen S, Morris S, Reznik J, Biros E, Paulik B, et al. The effects of shockwave therapy on musculoskeletal conditions based on changes in imaging: a systematic review and meta-analysis with meta-regression. *BMC Musculoskelet Disord*. (2020) 21:275. doi: 10.1186/s12891-020-03270-w

27. Worth AJ, Sandford M, Gibson B, Stratton R, Erceg V, Bridges J, et al. Causes of loss or retirement from active duty for New Zealand police German shepherd dogs. *Anim Welf*. (2013) 22:167–74. doi: 10.7120/09627286.22.2.167

28. Wirth KE, Rein DB. The economic costs and benefits of dog guides for the blind. *Ophthalmic Epidemiol*. (2008) 15:92–8. doi: 10.1080/09286580801939353

29. US Government Accountability Office. Welfare of federal working dogs In: *Report to congressional committees* (2022) GAO-23-104489). Available at: https://www.gao.gov/assets/gao-23-104489.pdf

30. Moore GE, Burkman KD, Carter MN, Peterson MR. Causes of death or reason for euthanasia in military working dogs: 927 cases (1993-1996). *J AVMA*. (2001) 219:209–14. doi: 10.2460/javma.2001.219.209

31. Farr BD, Ramos MT, Otto CM. The Penn vet working dog center fit to work program: a formalized method for assessing and developing foundational canine physical fitness. *Front Vet Sci*. (2020) 7:470. doi: 10.3389/fvets.2020.00470

frontiers | Frontiers in Veterinary Science

TYPE Brief Research Report
PUBLISHED 14 February 2024
DOI 10.3389/fvets.2024.1335939

Check for updates

OPEN ACCESS

EDITED BY
David Levine,
University of Tennessee at Chattanooga, United States

REVIEWED BY
Barbara Bockstahler,
University of Veterinary Medicine Vienna, Austria
James Edward Miles,
University of Copenhagen, Denmark

*CORRESPONDENCE
Nina R. Kieves
✉ kieves.1@osu.edu

RECEIVED 09 November 2023
ACCEPTED 02 February 2024
PUBLISHED 14 February 2024

CITATION
Kieves NR, Shoben A and Markley AP (2024) Risk factors for the development of stifle injuries in canine agility athletes. *Front. Vet. Sci.* 11:1335939. doi: 10.3389/fvets.2024.1335939

Risk factors for the development of stifle injuries in canine agility athletes

Nina R. Kieves[1]*, Abigail Shoben[2] and Arielle Pechette Markley[1]

[1]Department of Veterinary Clinical Sciences, College of Veterinary Medicine, The Ohio State University, Columbus, OH, United States, [2]Division of Biostatistics, College of Public Health, The Ohio State University, Columbus, OH, United States

Objectives: Our aim was to determine risk factors for developing stifle injuries in canine agility athletes. We hypothesized that increased weight, increased frequency of competing, and greater number of runs/day would increase risk.

Study design: Internet based survey, $n = 4{,}197$.

Methods: Individuals with at least one dog who had competed in agility in the past 3 years were eligible. Injury history was defined as an injury to the stifle that kept the dog from participating in agility for >1 week. Logistic regression models were used to estimate associations between variables of interest and injury history.

Results: Handlers of 216 dogs reported a history of injury. The majority were cranial cruciate ligament (CCL) injury (101/216), and patella luxation (40/216). In the final model, five variables were independently associated with odds of stifle injury (in addition to age). Heavier dogs (adjusted for height), Border Collies, male dogs neutered <10 months, female dogs spayed before their first heat cycle, handlers aged 18–24, and teeter contact behavior were associated with increased risk.

Conclusion: Heavier dogs were more likely to report injury, but there was no association with injury and increased number of competition days, or runs/day. The Border Collie breed was at the highest risk of injury. There was substantial risk for stifle injury with early spay/neuter. Additionally, a significant increase in risk of injury was reported for younger (18–24) vs. older handlers (65+). Athlete fitness level, conformation, and genetic predisposition to injury may play the most significant role in the development of injury.

KEYWORDS

agility, canine, stifle injury, risk factor, canine athlete

1 Introduction

Canine agility is a highly physical sport with frequent abrupt turns taken at high speed, coupled with running and jumping, and the need to navigate obstacles that change in elevation. Courses include numerous obstacles that dogs must complete, with the goal of completing the course in the shortest time with no errors. The physical demands of these activities place significant stress on the dog's musculoskeletal system, particularly on the joints. Injury rates of up to 42% have been reported in the literature for dogs competing in agility (1–5). Thoracic limb injury is most commonly reported including injury to the shoulder and paws (1–3).

However, one study reported pelvic limb injuries to be more common than thoracic limb injuries (4).

One of the most common debilitating orthopedic injuries an athlete can suffer is a knee injury. In humans, injury is often suffered during athletic events that require similar lateral cutting motions such as dogs undergo while competing in agility. Stifle injury in dogs competing in agility has been reported as high as 13% of injuries in one study (1), and 10% in another, with over 75% of these being classified as severe (6).

Stifle disease is a significant health concern for agility dogs, particularly if the injury is to the cranial cruciate ligament (CCL), as it is documented that these dogs have a low chance of returning to sport (7). Treatment of CCL disease is also costly financially to the handler/owner and carries with it a significant loss of competition time. Given the impact that injury to the stifle can have on a dog's agility career, our aim was to evaluate risk factors associated with developing stifle injury while participating in canine agility competitions. We hypothesized that increased weight, along with increased frequency of competing and increased number of runs per day of competition would increase risk of stifle injury.

2 Materials and methods

2.1 Study design

An internet-based survey, in English, was distributed via the internet with approval by the institutional review board at The Ohio State University using Qualtrics survey software (Qualtrics; Provo, UT). Specifics of this survey and results were previously published (1, 8). Briefly, individuals with at least one dog who had competed in agility in the past 3 years were eligible to complete the survey.

Stifle injury history was defined as an injury to the stifle that kept the dog from participating in agility for over a week. All participating owners were asked several questions about demographic variables (for handler and dog), training variables (e.g., age starting training each obstacle, method used for training contact and weave obstacles, trained contact obstacle behavior), and competition history (frequency of competing, runs per competition day, frequency of national and international competition, and frequency of competing on various surfaces). Owners reporting a stifle injury were asked additional follow up questions regarding the injury.

2.2 Statistical analysis

Statistical analysis was performed with commercially available software (Stata version 15.1, StataCorp, College Station, TX). Logistic regression models were used to estimate possible associations between variables of interest and stifle injury history. All models were adjusted for dog age to account for differences in exposure time for injury history. For the three pre-specified variables of interest (height and weight together, number of competition weekends per year, and typical number of runs per day), we tested each for an association in models that only adjusted for dog age. Given the lack of information on risk factors for stifle injury in the literature, we also considered a broader set of candidate variables via a stepwise model building process. All candidate variables were first assessed for univariate association with injury; variables significant at $p < 0.20$ were kept for future model building. Then three models were built via backward selection using blocks of variables (demographic, training, and competition factors). Variables that were significant in the stepwise model building at $p < 0.20$ were kept for consideration in the final model. The final model was built via backward selection until all included variables were associated with injury at $p < 0.05$.

3 Results

Complete demographic data related to this study population has been previously published (1). The most common breeds represented were Border Collie ($n = 1{,}052$), mixed breed ($n = 616$), and Australian Shepherd ($n = 312$). Mean age of the dogs at the time of survey was 6.3 ± 2.6 years.

Of the 4,197 dogs in the sample, 216 (5.2%) had a history of stifle injury. Nearly half (46.8%) of dogs reporting a stifle injury reported a cranial cruciate ligament (CCL) rupture (101/216). Other stifle injuries reported by more than 5 dogs were: medial luxating patella (26, 12.0%), arthritis (16, 7.4%), lateral luxating patella (14, 6.5%), medial collateral ligament sprain (13, 6.0%), lateral collateral ligament sprain (12, 5.6%), and caudal cruciate rupture (6, 2.8%). The exact diagnosis was reported to be unknown for 37 dogs (17%). Owners reported that they knew or suspected the injury occurred in competition or practice for 30% of dogs (65/214), while 45% ($n = 97$) said it did not and 24% ($n = 52$) were unsure. These percentages were nearly identical for the 101 CCL rupture injuries reported: 32% (32/101) in competition or practice; 46% (46/101) not in competition or practice, and 23% (23/101) were unsure.

In models adjusting only for dog age, body characteristics (height and weight) were associated with stifle injury risk, with heavier dogs (of the same height) having a higher odds of stifle injury (OR: 1.27 per 10 pounds (4.5 kilograms) heavier; 95% CI: 1.12 to 1.44) and taller dogs (of the same weight) having lower odds of stifle injury (OR: 0.73 per 4 inches (10.2 centimeters) shorter; 95% CI: 0.59 to 0.91). Number of trial weekends per year was not associated with odds of stifle injury ($p = 0.99$) with all groups (<5 weeks per year up to 26+ weekends per year) having similar odds of injury. Similarly, number of runs per trial day was not associated with odds of stifle injury ($p = 0.46$).

In the final model built via stepwise selection (Table 1; Figure 1), five variables were independently associated with odds of stifle injury (in addition to age). Body characteristics (height and weight) were associated with stifle injury, with taller dogs having lower odds of developing a stifle injury and heavier dogs (adjusted for height) having increased odds of injury. The other four variables in the final model were breed, spay/neuter status, handler age, and teeter contact behavior. Among breeds, Border Collies were at higher risk and there were minimal differences noted among other breed groups. Male dogs neutered before 10 months and female dogs spayed before their first heat cycle had markedly higher reported rates of stifle injury compared to all other sex/neuter groups that had generally similar odds of stifle injury. There was a notable decrease in odds as handler age increased, with the highest odds of injury observed among dogs of the youngest handlers (18–24) and the lowest among dogs of handlers aged 65 years and older (OR: 0.35). For the teeter contact, dogs that were either not trained to perform a specific behavior at the end of the teeter or dogs

TABLE 1 Odds ratios from final model built using stepwise selection.

	Adjusted OR final model	*p*-value
Dog Age (per 1 year older)	1.19 (1.13, 1.25)	<0.0001
Height & Weight		<0.0001
Height (per 4 in (10.2 cm) taller)	0.61 (0.47, 0.80)	
Weight (per 10 lbs. (4.5 kg) heavier)	1.39 (1.20, 1.60)	
Breed		0.029
Border Collie	1.63 (1.10, 2.40)	
Mixed Breed	0.76 (0.46, 1.24)	
Shetland Sheepdog	0.92 (0.46, 1.86)	
Australian Shephard	0.72 (0.36, 1.43)	
Other	REFERENCE	
Sex		0.0001
Male, Intact	REFERENCE	
Female, Intact	1.26 (0.63, 2.50)	
Male, Neutered <10 months	2.32 (1.27, 4.26)	
Male, Neutered 10–18 months	1.08 (0.57, 2.05)	
Male, Neutered >24 months	0.89 (0.45, 1.78)	
Female, Spayed <1 cycle	2.81 (1.62, 4.88)	
Female, Spayed 1 cycle	1.27 (0.64, 2.53)	
Female, Spayed >1 cycle	1.11 (0.60, 2.05)	
Handler current age		0.041
18–24	REFERENCE	
25–34	0.92 (0.43, 1.96)	
35–44	0.89 (0.42, 1.87)	
45–54	0.78 (0.37, 1.63)	
55–64	0.71 (0.35, 1.46)	
65+	0.35 (0.15, 0.80)	
Teeter contact		0.039
2 on 2 off	REFERENCE	
4 on (down)	0.95 (0.51, 1.75)	
4 on (standing)	0.86 (0.59, 1.25)	
No specific behavior	0.34 (0.13, 0.86)	
Other	0.30 (0.11, 0.83)	

performing a different behavior than the most common training options, had lower risk of reporting a history of stifle injury.

4 Discussion

While we found the expected association between heavier dogs and stifle injury history, there was no association with report of injury and an increased number of competition days, or runs per day. Therefore, our hypothesis was partially accepted. The lack of association of increased injury risk with increased number of competition days and/or runs may indicate that there truly is no association with increased agility-specific activity and stifle injury. It could also be a reflection of overall training load. If a dog trains substantially but does not compete often, their overall time under load could be similar to a dog that trains little but competes frequently. Prospective training data would need to be collected over the duration of a dog's competitive lifespan to elucidate such information. Our group has previously evaluated the effect of training load on injury risk and found that dogs who train very little, or for >120 h per week had a higher risk of developing injury than dogs who trained an intermediate amount (9). However, this study evaluated overall risk of injury while competing in agility, not specific types of injury. The lack of association observed between increased injury risk and number of competition days may also reflect a scenario in which dogs who are not as fit, or have had a stifle injury, are not entered into as many competitions or runs during competition by their handler as compared to those dogs who are healthy. Without training data, and prospective evaluation of fitness levels, we cannot assess these factors.

In the adjusted model, the Border Collie breed was at the highest risk of reporting stifle injury as compared to other breeds, with no other common agility breed (Australian Shepherd, Shetland Sheepdog, or mixed breed) showing an increased risk of injury. Border Collies competing in agility have been previously reported as having a higher risk factor of injury overall (1). In a previous report evaluating CCL injury risk in the general population, Border Collies were the 29th most common breed to report CCL injury (10). There is likely geographic variability in injury given that Engdahl found Boerboel's and Dogo Canario to have the highest rate of development of CCL injury in Sweden (11). We were unable to specifically evaluate risk for breeds known to be considered high risk for CCL injury (10) as they were not highly represented in this survey. Therefore, it is possible, due to the sample size for some of these breeds (i.e., Labrador Retriever), that we were unable to capture a significant increase in risk in these populations. Furthermore, we evaluated overall stifle risk injury, not only CCL injury.

Further study is needed into why Border Collies competing in agility may be at a higher risk of developing stifle injury including CCL injury than the general population of Border Collies. It may be related to genetics of the breed, breed conformation, or their speed and high drive during competitions, which have become even more complex and challenging over time. Contrary to our finding here that the Border Collie is at higher risk for developing stifle disease, a recent publication evaluating risk factors associated with CCL injury in agility dogs did not find the Border Collie to be at a higher risk for injury than other breeds (12). Our finding of increased risk for Border Collies developing stifle injury was especially high after adjusting for dog height and weight when compared to other breeds evaluated. This adjustment was not done in the Sellon et al. study (12), which could also explain the differences seen between these two studies. Again, our study assessed risk for all types of stifle injury, of which CCL injury was the highest reported injury, but this difference could also account for the increased risk found here.

The majority of stifle injuries reported here were CCL injuries, which pose a substantial potential loss of career for these athletes, as only 65% of agility dogs return to sport following tibial plateau leveling osteotomy (TPLO) surgery for treatment of CCL injury (7).

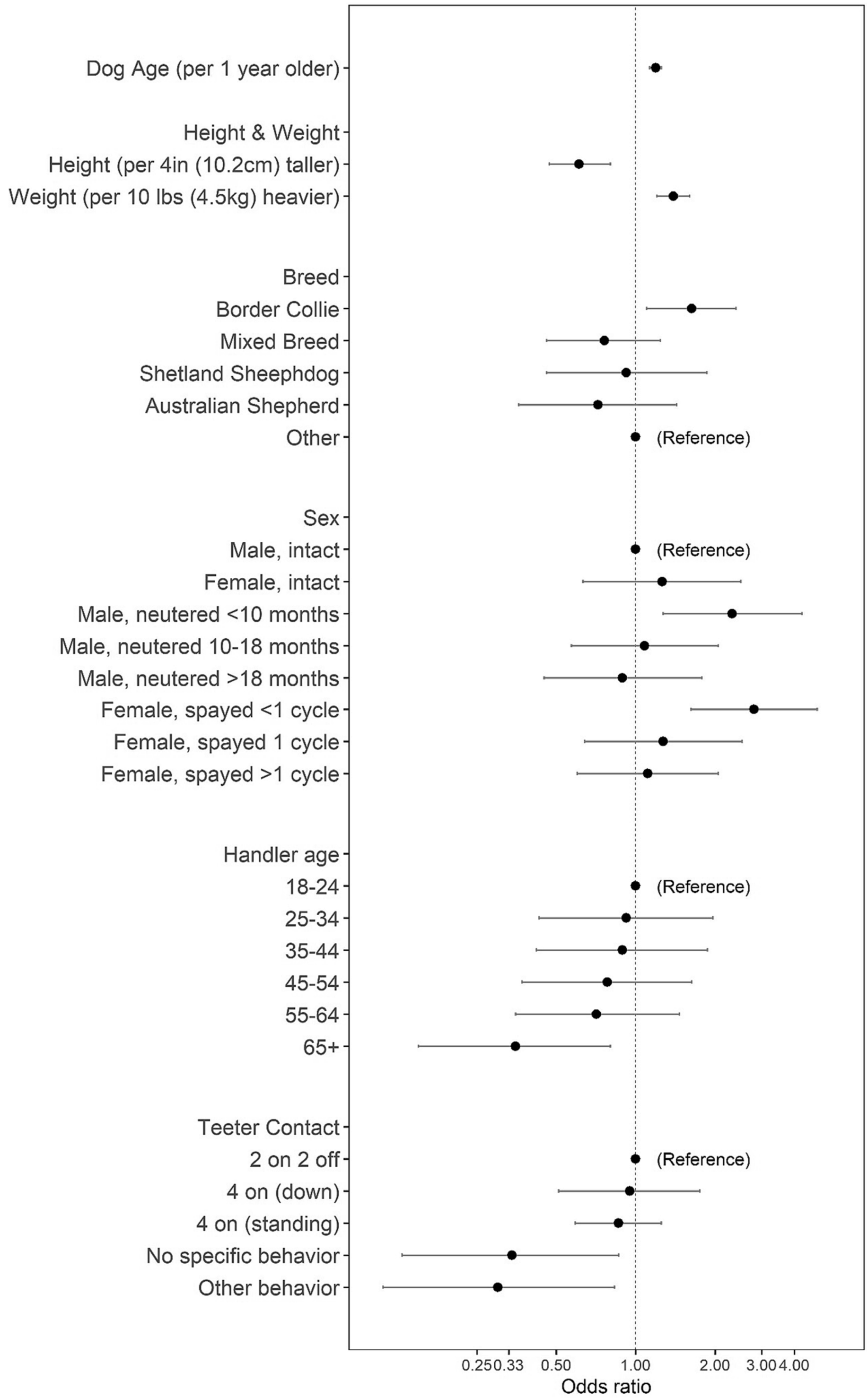

FIGURE 1
Graphical display of the odds ratios for history of stifle injury from the final model built using stepwise selection.

In human medicine a higher percentage of patients are reported to return to sport at 80% following anterior cruciate ligament (ACL) reconstruction surgery. However, only 65% of them return to their pre-injury level of performance and only 55% return to a competitive level of sport (13). This is despite studies showing that dogs undergoing TPLO have a return to near normal ground reaction forces as soon as 150 days after surgery (14, 15). Therefore, it is unknown why dogs may not return to competition despite returning to "normal" function as evaluated by force plate. Given these data, clients should be warned that when CCL injury is sustained, return to sport, particularly return to highly competitive levels of sport, may not be possible. Setting appropriate expectations early in the process of recovery should improve clinician-client relationships. It is currently unknown why such a low percentage of dogs return to sport. This could indicate that competitive agility dogs do not have the standard expected outcome with the stabilization technique elected, or it may be the handler's choice to no longer compete with that dog following injury and treatment, as opposed to the dog's lack of physical ability to perform agility activities. Furthermore, we do not know what degree of osteoarthritis these dogs had, nor what their meniscal status was, both of which likely play a role in ability to return to full competitive level of agility. We also cannot determine based on the survey data collected what the nature of the CCL injury in terms of a possible traumatic tear vs. the more commonly sustained degenerative injury to which dogs are prone. Histopathology of the CCL would be required to determine the ultimate cause of injury, and this is not commonly performed.

It may be that conformation and genetic predisposition to CCL injury play the most significant role in the development of this injury (16). In human ACL injury, the most common mechanism of injury is sudden pivoting or cutting maneuver which often occur during sports such as soccer, basketball, and football. Non-contact injury is also reported, with risk factors associated with tearing of the ACL including sex (female > male), and numerous bone morphologic characteristics such as lateral femoral condylar ratio, notch width index, and lateral posterior tibial slope (17). In dogs, one study found an association between tibial anatomical-mechanical axis angle and CCL injury (18). Due to the nature of this survey, conformational and genetic factors were not able to be assessed. The survey did ask whether the injury was thought to have occurred during competition or training, with approximately 30% of owners reporting that the injury (either CCL or other) occurred during agility training or competition. However, the complex etiology of CCL disease specifically makes it challenging to determine whether stifle injuries reported during training and competition were truly acute, traumatic injuries, or progression of previous chronic partial tears that were a result of other underlying risk factors. A study evaluating the cause of CCL injury in field trial dogs found owners to be inaccurate in their understanding of and assessment of how the injury occurs (i.e., traumatic vs. degenerative) (19). Therefore, we cannot say if any of the injuries reported were truly traumatic while actively participating during agility, or in fact whether they might have occurred regardless of the dog's participation in agility activities. For instance, dogs that sustained a CCL injury may have done so even without participation in agility at all during their lifetimes.

An increased risk of stifle injury with increased body weight was identified. Sellon and Marcellin-Little, also reported an association between increasing dog weight and CCL injury in a population of agility dogs (12). Obesity has been found to be associated with CCL injury (10, 20–22), and obesity is more common in neutered dogs (6). Heavier weight, as adjusted for height, was found to be a risk factor for injury in this survey, which may support those previous findings (13). Athlete fitness level may also play a substantial role in the development of CCL injury. Sellon and Marcellin-Little reported that agility dogs performing routine core strength and balance exercises had lower risk of reported CCL injury (12). Muscle activation has been proposed as a contributing factor to the development of CCL injury in dogs (23), as well as humans (24).

Early spay/neuter was associated with a substantial increase in risk for stifle injury. Previous reports have suggested that early spay/neuter may increase risk of CCL injury (10, 20, 21), and the majority of stifle injuries reported here were CCL injury, which may have helped drive this result. Previous reports have also shown an overall increased risk in the development of orthopedic disease in larger dogs with early spay/neuter (25). Given the small number of other injuries reported, we were unable to statistically evaluate CCL injury as compared to other stifle injuries to better assess which risk factors are most associated with which specific stifle injuries. This should be prospectively studied in the future to determine if the risk factors reported here influence specific stifle injuries (CCL vs. patella vs. other). Ultimately, additional prospective work is needed to best assess what factors may decrease risk of developing CCL injury in agility dogs including whether targeted strengthening programs may help prevent CCL and stifle injury in general in dogs.

Similar to previous studies (26, 27), we found a significant increase in risk of injury history in dogs with younger handlers (18–24) as compared to older handlers (particularly 65+). Younger handlers are likely to be less experienced and may not be as precise with their handling, which could result in more reactionary movements from the dog, such as more sudden changes in speed and turning. It is also possible that they may have started agility as a hobby with their pet dog, who may not be the fittest or conformationally sound and thus be more prone to injury. Additionally younger handlers may not pick up on subtle signs of injury as well as older, more experienced handlers, therefore allowing their dog to continue competing and ultimately leading to progression of injury. The finding that dogs either not trained to perform a specific behavior at the end of the teeter, or dogs performing a different behavior than the most common options, have a lower risk for reporting a history of stifle injury may be related to handler experience, particular training techniques, or specific biomechanical forces incurred during teeter performance.

Inherit limitations of a survey include potential inaccuracies due to participant recall and handler-reported data without confirmation by a veterinarian. Self-selection bias may also result in the sample selection not being representative of the total agility dog population. Furthermore, we were unable to assess risk factors for specific stifle injuries due to small numbers reported here. Lastly, while injuries are reported in dogs performing agility, we could not elucidate whether the injuries occurred specifically due to agility training or competition or occurred secondary to performing agility. The injuries might have occurred in these dogs regardless of whether they actively participated in agility or not.

This survey provides insight into potential risk factors associated with all stifle injuries in agility athletes. The potential risk for stifle injury with early spay/neuter should be further explored. While we have begun to have a better understanding of musculoskeletal injuries due to increased availability of advanced imaging, there remains a lack of understanding of the kinetics and kinematics of dogs participating in sport, and how it relates to injury risk. Such studies are needed to enable us to make appropriate recommendations for prevention of injury. This particularly true regarding CCL injury given its significant impact on athletic capabilities following injury.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

NK: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. AS: Data curation, Formal analysis, Methodology, Writing – review & editing. AM: Data curation, Formal analysis, Methodology, Writing – review & editing, Investigation, Project administration.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Pechette Markley A, Shoben AB, Kieves NR. Internet-based survey of the frequency and types of orthopedic conditions and injuries experienced by dogs competing in agility. *J Am Vet Med Assoc*. (2021) 259:1001–8. doi: 10.2460/javma.259.9.1001

2. Levy M, Hall C, Trentacosta N, Percival M. A preliminary retrospective survey of injuries occurring in dogs participating in canine agility. *Vet Comp Orthop Traumatol*. (2009) 22:321–4. doi: 10.3415/VCOT-08-09-0089

3. Kerr ZY, Fields S, Comstock RD. Epidemiology of injury among handlers and dogs competing in the sport of agility. *J Phys Act Health*. (2014) 11:1032–40. doi: 10.1123/jpah.2012-0236

4. Evanow JA, Van Deventer G, Dinallo G, et al. Internet survey of participant Demogrpahics and risk factors for injury in competitive agility dogs. *VCOT Open*. (2021) 4:e92–8. doi: 10.1055/s-0041-1735843

5. Inkilä L, Hyytiäinen HK, Hielm-Björkman A, Junnila J, Bergh A, Boström A. Part II of Finnish agility dog survey: agility-related injuries and risk factors for injury in competition-level agility dogs. *Animals*. (2022) 12:227. doi: 10.3390/ani12030227

6. Cullen KL, Dickey JP, Bent LR, Thomason JJ, Moëns NMM. Internet-based survey of the nature and perceive causes of injury to dogs participating in agility trianing and competion events. *J Am Vet Med Assoc*. (2013) 243:1010–8. doi: 10.2460/javma.243.7.1010

7. Heidorn SN, Canapp SO Jr, Zink CM, et al. Rate of return to agility competition for dogs with cranial cruciate ligament tears asscoiated with tibial plateau leveling osteotomy. *J Am Vet Med Assoc*. (2018) 253:1439–44. doi: 10.2460/javma.253.11.1439

8. Pechette Markley A, Shoben AB, Kieves NR. Internet survey of risk factors associated with training and competition in dogs competing in agility competitions. *Front Vet Sci*. (2022) 8:791617. doi: 10.3389/fvets.2021.791617

9. Pechette Markley A, Shoben AB, Kieves NR. Training load and relationship to injury risk in dogs competing in agility competitions. *VCOT Open*. (2023) 6:A1–A11. doi: 10.1055/s-0043-1768902

10. Witsberger TH, Villamil JA, Schultz LG, Hahn AW, Cook JL. Prevelance of and risk factors for hip dysplasia and cranial cruciate ligmaent deficiency in dogs. *J Am Vet Med Assoc*. (2008) 232:1818–24. doi: 10.2460/javma.232.12.1818

11. Engdahl K, Emanuelson U, Höglund O, Bergström A, Hanson J. The epidemiology of cruciate ligament rupture in an insured Swedish dog population. *Sci Rep*. (2021) 11:9546. doi: 10.1038/s41598-021-88876-3

12. Sellon DC, Marcellin-Little DJ. Risk factors for cranial cruciate ligament rupture in dogs participating in canine agility. *BMC Vet Res*. (2022) 18:39. doi: 10.1186/s12917-022-03146-2

13. Ardern CL, Taylor NF, Feller JA, Webster KE. Fifty-five per cent return to competitive sport following anterior cruciate ligament reconstruction surgery: an updated systematic review and meta-analysis including aspects of physical functioning and contextual factors. *Br J Sports Med*. (2014) 48:1543–52. doi: 10.1136/bjsports-2013-093398

14. Amimoto H, Koreeda T, Wada N. Evaluation of recovery of limb function by use of force plate gait analysis after tibial plateau leveling osteotomy for management of dogs with unilateral cranial cruciate ligament rupture. *Am J Vet Res*. (2019) 80:461–8. doi: 10.2460/ajvr.80.5.461

15. Krotscheck U, Nelson SA, Todhunter RJ, Stone M, Zhang Z. Long term functional outcome of Tibial tuberosity advancement vs. Tibial plateau leveling osteotomy and extracapsular repair in a heterogeneous population of dogs. *Vet Surg*. (2016) 45:261–8. doi: 10.1111/vsu.12445

16. Baird AE, Carter SD, Innes JF, Ollier WE, Short AD. Genetic basis of cranial cruciate ligament rupture (CCLR) in dogs. *Connect Tissue Res*. (2014) 55:275–81. doi: 10.3109/03008207.2014.910199

17. Choi NH, Lee DM, Victoroff BN. Bone morphological characteristics as risk factors for anterior cruciate ligament injury: comparison between contact and noncontact injury. *Orthop J Sports Med*. (2023) 11:23259671231179757. doi: 10.1177/23259671231179757

18. Guénégo L, Payot M, Charru P, Verwaerde P. Comparison of tibial anatomical-mechanical axis angle between predisposed dogs and dogs at low risk for cranial cruciate ligament rupture. *Vet J*. (2017) 225:35–41. doi: 10.1016/j.tvjl.2017.04.011

19. Hynes J, Manfredi JM, Shull SA. Cranial cruciate ligament disease is perceived to be prevalent and is misunderstood in field trial sport. *J Am Vet Med Assoc*. (2023):1–6. doi: 10.2460/javma.23.01.0004

20. Duval JM, Budsberg SC, Flo GL, Sammarco JL. Breed, sex, and body weight as risk factors for rupture of the cranial cruciate ligament in young dogs. *J Am Vet Med Assoc*. (1999) 215:811–4. doi: 10.2460/javma.1999.215.06.811

21. Spinella G, Arcamone G, Valentini S. Cranial cruciate ligament rupture in dogs: review on biomechanics, Etiopathogenetic factors and rehabilitation. *Vet Sci*. (2021) 8:186. doi: 10.3390/vetsci8090186

22. Santarossa A, Gibson TWG, Kerr C, Monteith GJ, Durzi T, Gowland S, et al. Body composition of medium to giant breed dogs with or without cranial cruciate ligament disease. *Vet Surg*. (2020) 49:1144–53. doi: 10.1111/vsu.13434

23. Adrian CP, Haussler KK, Kawcak C, Reiser RF 2nd, Riegger-Krugh C, Palmer RH, et al. The role of muscle activation in cruciate disease. *Vet Surg*. (2013) 42:765–73. doi: 10.1111/j.1532-950X.2013.12045.x

24. Bencke J, Aagaard P, Zebis MK. Muscle activation during ACL injury risk movements in young female athletes: a narrative review. *Front Physiol*. (2018) 9:445. doi: 10.3389/fphys.2018.00445

25. Hart BL, Hart LA, Thigpen AP, Willits NH. Assisting decision-making on age of neutering for mixed breed dogs of five weight categories: associated joint disorders and cancers. *Front Vet Sci*. (2020) 7:472. doi: 10.3389/fvets.2020.00472

26. Cullen KL, Dickey JP, Bent LR, Thomason JJ, Moëns NM. Survey-based analysis of risk factors for injury among dogs participating in agility training and competition events. *J Am Vet Med Assoc*. (2013) 243:1019–24. doi: 10.2460/javma.243.7.1019

27. Sundby AE, Pechette Markley A, Shoben AB, Kieves NR. Internet survey evaluation of demographic risk factors for injury in canine agility athletes. *Front Vet Sci*. (2022) 9:869702. doi: 10.3389/fvets.2022.869702

TYPE Original Research
PUBLISHED 27 February 2024
DOI 10.3389/fvets.2024.1356061

Evaluating injuries and illnesses that occurred during the Yukon Quest International sled dog race, 2018–2020

Jenna C. Hattendorf[1], Michael S. Davis[2] and Cristina M. Hansen[3]*

[1]College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, CO, United States, [2]Department of Physiological Sciences, College of Veterinary Medicine, Oklahoma State University, Stillwater, OK, United States, [3]Department of Veterinary Medicine, College of Natural Science and Mathematics, University of Alaska Fairbanks, Fairbanks, AK, United States

Check for updates

OPEN ACCESS

EDITED BY
Heidi Reesink,
Cornell University, United States

REVIEWED BY
Sara Connolly,
University of Illinois at Urbana-Champaign, United States
Janice L. Huntingford,
Chi University, United States
Matthew Warren Brunke,
Veterinary Referral Associates, United States

*CORRESPONDENCE
Cristina M. Hansen
cmhansen@alaska.edu

RECEIVED 15 December 2023
ACCEPTED 31 January 2024
PUBLISHED 27 February 2024

CITATION
Hattendorf JC, Davis MS and Hansen CM (2024) Evaluating injuries and illnesses that occurred during the Yukon Quest International sled dog race, 2018–2020.
Front. Vet. Sci. 11:1356061.
doi: 10.3389/fvets.2024.1356061

Introduction: The purpose of this study was to evaluate medical record data from the 2018–2020 Yukon Quest International Sled Dog race to examine injury patterns and risk factors for dogs competing in multi-day ultra-endurance events. Specifically, we summarized injuries and illnesses that resulted in canine athletes being removed ("dropped") from competition, and in orthopedic injuries diagnosed in both dropped and finished dogs.

Methods: The records of 989 dogs that started the race were examined, but only records from dogs in teams that went on to finish the race were included, for a total of 711 records.

Results and discussion: Three hundred and sixty five dogs (51.3%) were noted to have at least one abnormal finding in their veterinary medical record during the race. Orthopedic injuries were most common, and 291 injuries were ultimately diagnosed in 234 dogs (32.9%). Ultimately, 206 dogs (29%) were dropped from competition, for any reason. The most common reasons for dropping dogs were orthopedic injuries (156 dogs; 188 injuries), gastrointestinal illness (22 dogs), and cardiorespiratory disease (7 dogs). Most orthopedic injuries in dropped dogs occurred in the thoracic limb (n = 121 dogs; 151 injuries). Of those, injuries to the shoulder were most common (n = 77), followed by injuries to the carpus (n = 59), and injury to the pelvic limb (n = 32). Carpal injuries were the most prevalent injury diagnosed in dogs that went on to finish the race (71 of 85 injuries). Carpal injuries were the most prevalent injuries overall in 2018 (51%) and 2019 (52%). In 2020, shoulder injuries were most prevalent (27%), suggesting that trail conditions may have differed between years. The majority of dogs with an orthopedic injury ultimately were removed from competition (156 of 234, or 66.6%), but the likelihood of finishing the race with an injury depended on the type of injury sustained; 71 of 130 dogs (54.6%) with a carpal injury went on to finish the race, whereas only 9 of 86 dogs with a shoulder injury (10.5%) went on to finish. The results of this study can assist mushers and veterinarians in preparing for races, and in decision making during endurance sled dog races.

KEYWORDS

Yukon Quest, orthopedic injuries, sled dog, dog mushing, canine sports medicine, veterinary medicine, canine orthopedic injuries, sled dog race

Introduction

Ultra-endurance sled dog racing consists of teams of 12–16 dogs competing on wilderness trails over distances from 300–1,000 miles. These races last 2–12 days, during which time the teams pass through multiple checkpoints staffed by race officials and veterinarians. Dogs are examined at these checkpoints, and dogs are removed from the team ("dropped") if the musher and/or veterinarian determine that the dog is unfit to continue in the race due to illness or injury. Typical race rules state that dogs cannot be replaced during a race; thus, dropping a dog results in a smaller team with less pulling power. In some instances, entire teams will elect to voluntarily withdraw or "scratch" from the race if circumstances suggest that continuing in the race is unlikely to be beneficial.

Several studies have been conducted to characterize the types of illnesses and injuries that occur in dogs during ultra-endurance racing. Von Pfiel et al. (1) documented orthopedic injuries sustained by dropped dogs during the 2011 Iditarod and associated injuries with various risk factors, including traveling speed and age. They documented that 43.3% of dropped dogs were dropped due to forelimb lameness, and 7.3% for hindlimb lameness, however this paper did not include data from dogs that finished the race. Many dogs (anecdotally, for example, those with carpal injuries) are diagnosed with mild to moderate orthopedic injuries, receive treatment and care on the trail, and are able to finish the race. One study did analyze records from both dropped and finished dogs competing in the Yukon Quest (2). That study characterized lameness as shoulder, carpal, or nonspecific, and examined records from 6 undefined locations during the race. That study documented forelimb lameness in 13.9% of all dogs (dropped and finished) competing in the Yukon Quest, but did not include a hindlimb lameness category. They also included diarrhea, cough, and "other disorder" reason for documenting dogs, but did not include other gastrointestinal or cardiorespiratory categories.

These previous studies provide a foundation for characterizing the types of illnesses and injuries that develop during ultra-endurance sled dog racing, but fail to provide a complete description of the risk factors for injury or for being dropped from a race. Therefore, the purpose of this study was to quantify and characterize the total number of orthopedic injuries and other illnesses incurred by all dogs competing in an ultra-endurance sled dog race, and also to examine the risk factors for dogs being dropped from that race in the hopes that this information will aid veterinarians who work with athletic dogs make decisions about their care.

Methods

Veterinary medical record (hereafter "vet book") data from 1,101 canine athletes that participated in the 1,000-mile Yukon Quest between 2018 and 2020 were compiled and analyzed. Each musher is allowed to have up to 16 dogs examined at pre-race veterinary checks, though they are allowed to start with 14 dogs. This provides them with 2 alternate dogs, should a dog incur an injury/illness in the weeks prior to the race start. During the race, mushers carry these vet books with them in their sleds as part of their mandatory gear. Upon arrival to each checkpoint, veterinarians read them and can follow-up with the health of individual dogs, and make entries about new exam findings in dogs.

The Yukon Quest Veterinary Team generally consists of 12 veterinarians and some veterinary support staff. Most of the veterinarians are general practitioners with an interest in working dogs, some are specialists in various fields, including sports medicine. Because of varying skill in the ability to diagnose orthopedic disease and the lack of diagnostic equipment on the trail, an exact cause of lameness is not always identified and vet book detail is sometimes lacking; i.e. some records state specifically that a shoulder is painful on extension vs. flexion or narrow the diagnosis to a particular musle, tendon, or joint. Some records simply state something akin to "shoulder injury." Therefore, we did not categorize injury beyond joint in this paper.

For this study, a database was created and managed in Microsoft Excel that consisted of each athlete's signalment, weight, body condition score (BCS) pre-race vital signs (temperature, pulse, respiratory rate) and physical examination findings, team notes, checkpoint physical examination findings, and the final disposition (finished, dropped, part of a scratched team, expired) of each dog.

Each dog's record was evaluated for the presence of an injury or illness that was mentioned at more than one checkpoint (indicating a persistent problem), required veterinary care, or caused the athlete to drop out of the race. These injuries were sorted into five categories: orthopedic, gastrointestinal (GI) disease/inappetence, cardiorespiratory disease, exertional rhabdomyolysis or other illness/injury. "Other Illness/Injury" included injuries or illnesses that occurred that did not fit the other categories, such as frost bite, harness rubs, and dogfight or other wounds. We also assigned a location of drop for each dog based on race quarter. Since the race alternates directions (Fairbanks to Whitehorse in even numbered years, and Whitehorse to Fairbanks in odd-numbered years), we cannot directly compare dogs dropped at each checkpoint. We divided the race into quarters based on milage as follows. In Fairbanks start years (even-numbered years): quarter 1 is from Fairbanks to Circle City (216 miles), quarter 2 is from Circle City to Dawson City (310 miles), quarter 3 is from Dawson City to Pelly Crossing (210 miles), and quarter 4 is from Pelly Crossing to Whitehorse (250 miles). In Whitehose start years (odd years) those quarters are reversed (Figure 1).

All statistical analyses were performed using R (3). Descriptive statistics (mean and standard deviation for continuous data, counts for categorical data) were calculated. We performed tests of equal proportions to determine whether the proportion of illnesses and injuries were different between years, and whether the location of dropped dogs (divided into race quarter) varied by year. Risk factors for individual dogs developing injuries or being dropped were assessed by fitting general linear models. Independent variables included demographic/trail factors (age, race direction, etc.) and dog illness/injury factors. Two models were evaluated: one assessing the affect of demographic/trail factors on the likelihood that a dog will develop an injury or be dropped from the race, and a second assessing whether or not dog illness/injury factors increase likelihood of being dropped. We did not include year and race direction in the same model, as those are directly related (in odd-numbered years the race direction is East to West, and vice versa). We further divided injuries into categories to determine which most likely would result in a dog being dropped. We only included dogs from teams that finished the race (i.e., excluding dogs that were dropped from teams that would go on to

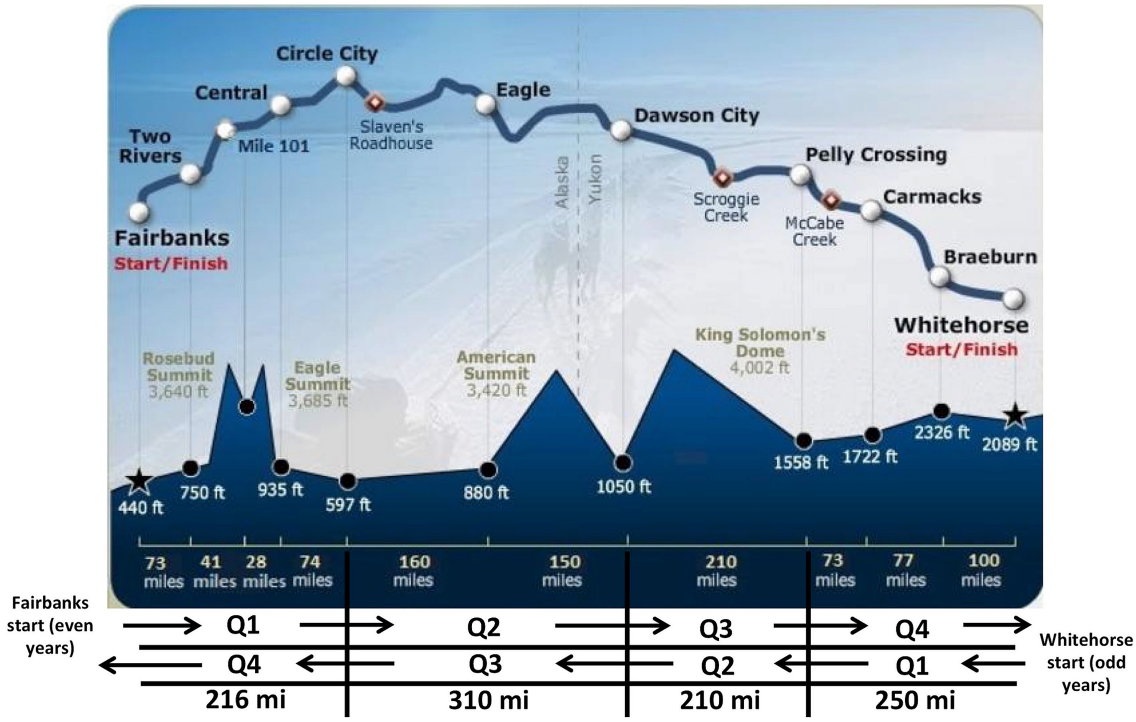

FIGURE 1
A map of the Yukon Quest trail superimposed over its elevation profile. The race alternates directions and starts in Fairbanks, AK (USA) in even-numbered years and in Whitehorse, YT (Canada) in odd-numbered years, so we cannot compare data checkpoint to checkpoint. We divided the race into quarters, as shown, to determine where dogs are likely to be dropped.

scratch or be withdrawn) in our analysis. An independent variable with $p < 0.05$ was considered significant.

Results

Demographics

One thousand one hundred and one (1101) dogs were examined at pre-race veterinary checks, which occur in the 2-weeks prior to the race start. 989 went on to start the race. We excluded records of dogs from teams that went on to scratch from the race, or were disqualified or withdrawn (278 dogs). The records from 711 dogs that started the race and were from teams that went on to finish were included in our analysis. The demographics (breed, age, sex, weight) of dogs included in this study are shown in Table 1.

Incidence of injuries

A total of 365 (51.3%) dogs experienced some type of injury or illness during the race. Two-hundred and six of those injured/ill athletes (56.4%) eventually dropped out of the race. In 2018, a total of 26.6% of dogs were dropped from the race (48 of 181); in 2019, 32% (121 of 378); and in 2020, 24.2% (37/153). These proportions were not statistically different between years ($p = 0.14$). The three most common reasons for dropping dogs during all 3 years analyzed were orthopedic injuries (156 dogs), GI illness or anorexia (22 dogs), and cardiorespiratory illness (7 dogs; Figure 2).

Among all dogs (those that finished and those that were dropped), orthopedic injuries were the most prevalent diagnosis in each year of the race (26.5% of dogs that started in 2018, 39.4% of dogs that started in 2019, and 24.2% of dogs that started in 2020), and most common reason for dropping dogs each year (32 dogs, 97 dogs, and 27 dogs, respectively). The overall number of orthopedic injuries diagnosed in all dogs is different between years ($p = 0.0004$).

The most common site of orthopedic injury in all dogs (dropped and finished) varied year to year (Figure 3). In 2018 and 2019, the largest proportion of injuries occurred in the carpal joint, at 50.9 and 52%, respectively. In 2020, however, relatively more shoulder injuries (27%) than carpal injuries (19%) occurred. The proportion of carpal injuries among all dogs varied between years ($p = 0.00002$). The proportion of shoulder and hindlimb injuries did not vary ($p = 0.75$ and 0.39, respectively). The proportion of carpal injuries out of all orthopedic injuries varied by year ($p = 0.007$). The proportion of shoulder and hindlimb injuries out of all orthopedic injuries did not vary ($p = 0.25$ and 0.06, respectively).

Orthopedic injuries in dropped dogs were divided by localization (Figure 4). Injuries of the thoracic limb were most common in dropped dogs (151 injuries in 121 dogs.) followed by injuries to the pelvic limb (32). Two dropped dogs experienced an injury to their axial skeleton. Three dogs' records reported that they were stiff/sore and could not localize an injury, or had an injury that was not well documented in the vet book (example, "lame" is all that is recorded).

TABLE 1 The average dog signalment 2018–2020.

	Average age	Age range	MI	FI	MC	FS	Average pre-race weight (kgs)	Alaskan Husky	Siberian Husky
2018	4.22	(1–8.5)	113	57	10	0	24.56	166	14
2019	4.22	(1–10)	211	147	18	2	24.27	350	28
2020	4.29	(2–8)	75	46	21	11	24.32	139	14
Total	4.24	(1–10)	399	250	49	13	24.38	655	56

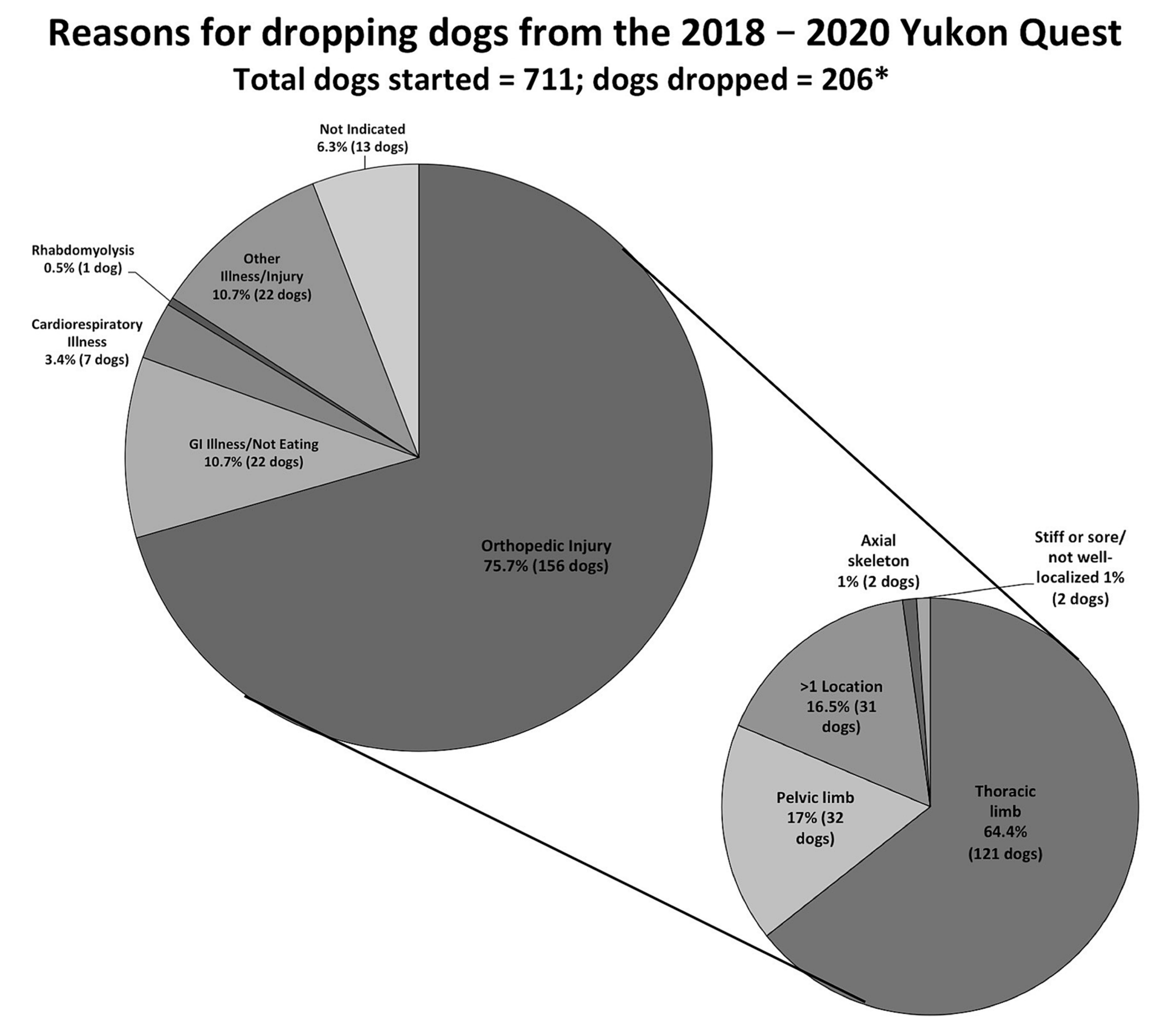

FIGURE 2
Reasons listed in veterinary medical records for dropping dogs during the 2018–2020 Yukon Quest. Orthopedic injuries are further characterized in the smaller pie. The records from 711 dogs from teams that would go on to finish the race are included. *Note that some dogs experienced multiple abnormalities so the number of reasons listed for dropping dogs exceeds the number of dropped dogs. Similarly, some dogs experienced multiple orthopedic injuries, so the number of injuries is greater than the number of dogs dropped for an orthopedic injury.

In the thoracic limb, shoulder injuries were most common in dropped dogs (77 injuries) followed by carpal injuries which occurred in 59 dropped dogs. Additional, less common thoracic limb injuries included those to the pectoral muscles (7 injuries), antebrachium (3 injuries), elbow (3 injuries), and other (2 injuries, including metacarpus and dewclaw injuries).

Seventy-eight dogs finished the Yukon Quest after sustaining some type of orthopedic injury. Some of those dogs experienced more

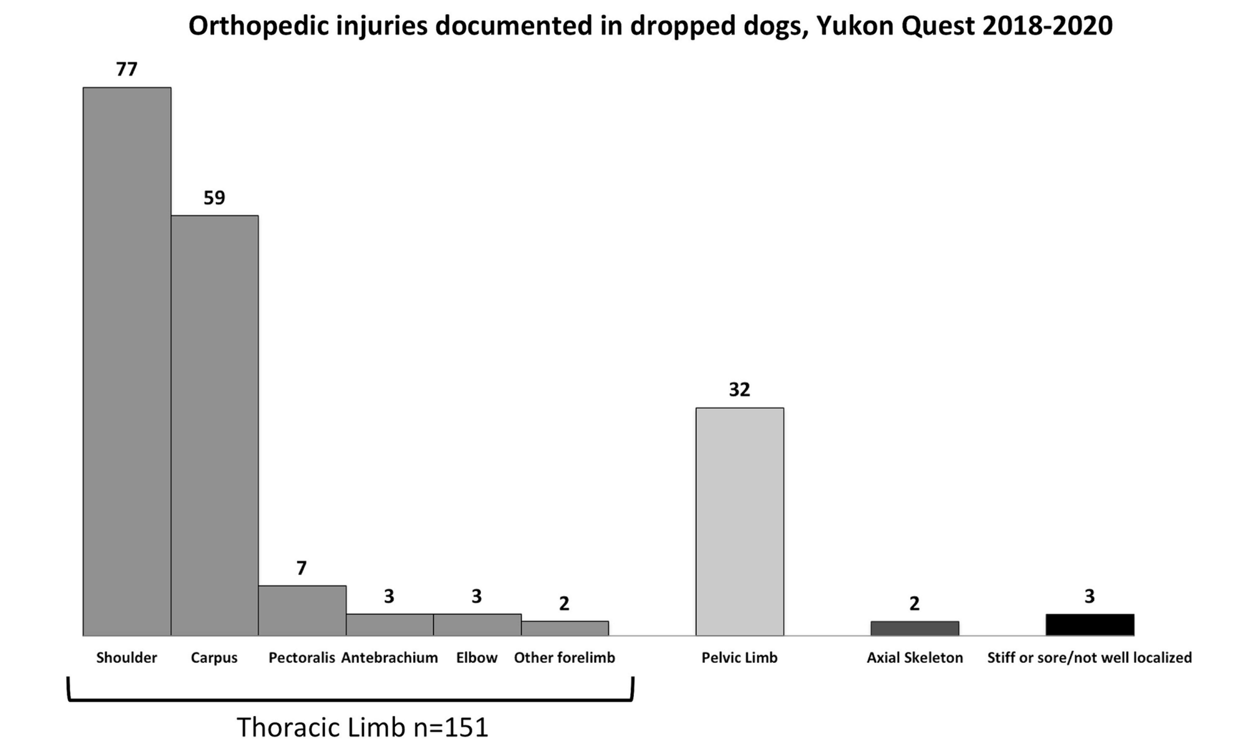

FIGURE 3
Proportions of carpal, shoulder, hindlimb, and other injuries diagnosed in dogs during the 2018–2020 Yukon Quest. The proportion of carpal injuries diagnosed was significantly different between years, as was the proportion of other injuries.

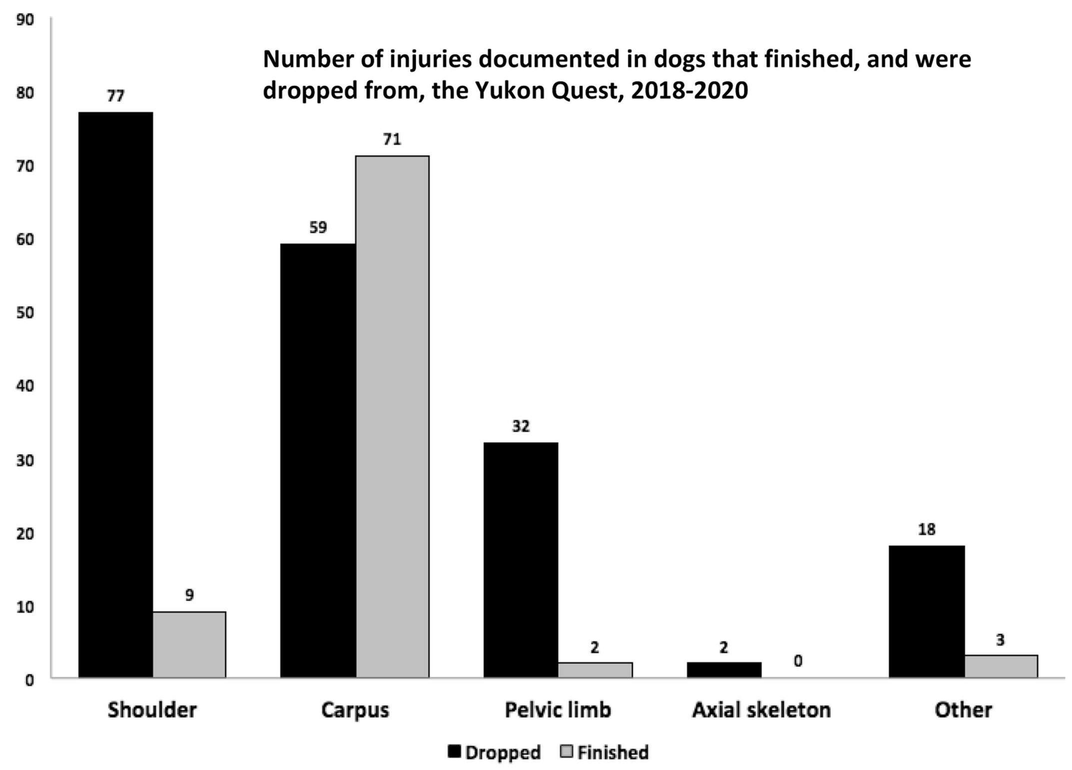

FIGURE 4
A summary of orthopedic injuries diagnosed in dropped dogs during the 2018–2020 Yukon Quest. Note that some dropped dogs were diagnosed with more than one injury, so there are more injuries documented here than there were dropped dogs due to injury in the previous figure.

than one injury, for a total of 85 injuries. These injuries were localized to compare to the injuries that occurred in dogs that were dropped from the race (Figure 5). In dogs that finished with an injury, the carpus was the most common site with 71 injuries (83.5%) noted, followed by 9 shoulder injuries (10.6%), 2 pelvic limb injuries (2.4%), and 3 other injuries (4%).

Out of the dogs that sustained a carpal injury, 54.6% (71 of 130) that sustained a carpal injury were able to finish the race, compared with only 9.4% of dogs (9 of 86) with shoulder injuries, 5.9% (2 of 34) pelvic limb injuries, and 0% (0 of 2) of axial skeleton injuries.

Drop location

The trail was divided into four quarters to determine if there were specific portions of the trail where dogs were more likely to be dropped (Figure 6). Tests of equal proportions confirm that in even-numbered (Fairbanks-start) years, significantly more dogs are dropped during Q1 ($p = 1.5 \times 10^{-9}$), and in odd-numbered (Whitehorse-start) years, most dogs are dropped during Q2 ($p = 0.001$).

Pre-race risk factor model results

The general linear model of dogs being dropped based on year (not race direction), breed, age, sex, and pre-race BCS found that Siberian huskies were less likely to be dropped ($p = 0.02$). Year ($p = 0.61$), age ($p = 0.24$), BCS ($p = 0.08$) and sex ($p = 0.84$ FS; 0.86 M; 0.28 MN) were not significant factors. When including direction (not year), Siberian huskies were still less likely to be dropped ($p = 0.018$). Direction appears to be a factor, with dogs less likely to be dropped in Fairbanks start years ($p = 0.049$). All other factors remain insignificant (age $p = 0.24$, BCS $p = 0.08$; FS $p = 0.94$, M $p = 0.76$, MN $p = 0.2$).

In our models testing effect of demographic and trail factors on the likelihood of dogs acquiring injuries (but not necessarily being dropped), when including year; neither year ($p = 0.87$), age ($p = 0.45$), pre-race BCS ($p = 0.36$), nor sex when compared to intact females (FS $p = 0.81$, M $p = 0.37$, MN $p = 0.28$) were significant factors. Siberian huskies are less likely to develop injury ($p = 0.003$). When including direction (rather than year), there is a strong effect of direction ($p = 0.0001$), with dogs more likely to be dropped when the race starts in Whitehorse. Siberian husky remains significant ($p = 0.004$), in that they appear to be less likely to be injured. Age ($p = 0.42$), pre-race BCS ($p = 0.34$), and sex (FS $p = 0.86$; M $p = 0.49$; MN $p = 0.49$) appear to not be significant factors.

Intra-race risk factor model results

When examining injury/illness and likelihood of being dropped, dogs diagnosed with an orthopedic injury ($p = 2 \times 10^{-16}$), with a cardiorespiratory abnormality ($p = 1.16 \times 10^{-5}$), or with an "other" illness/injury ($p = 6.86 \times 10^{-8}$), were much more likely to be dropped. Dogs diagnosed with a gastrointestinal illness were not likely to be dropped ($p = 0.21$). Interestingly, dogs with rhabdomyolysis in this model were not more likely to be dropped, however, of the 2 dogs that

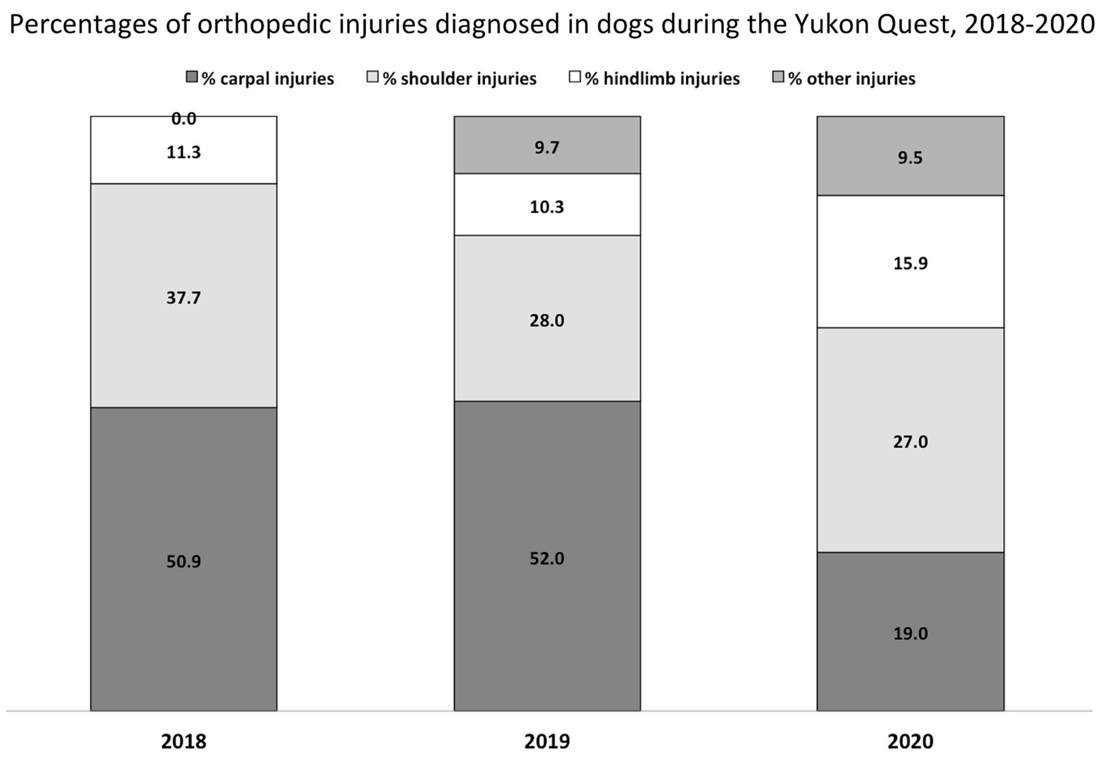

FIGURE 5
Orthopedic injuries documented in both dogs that finished, and were dropped from, the 2018–2020 Yukon Quest. Note that some dogs were diagnosed with more than one injury.

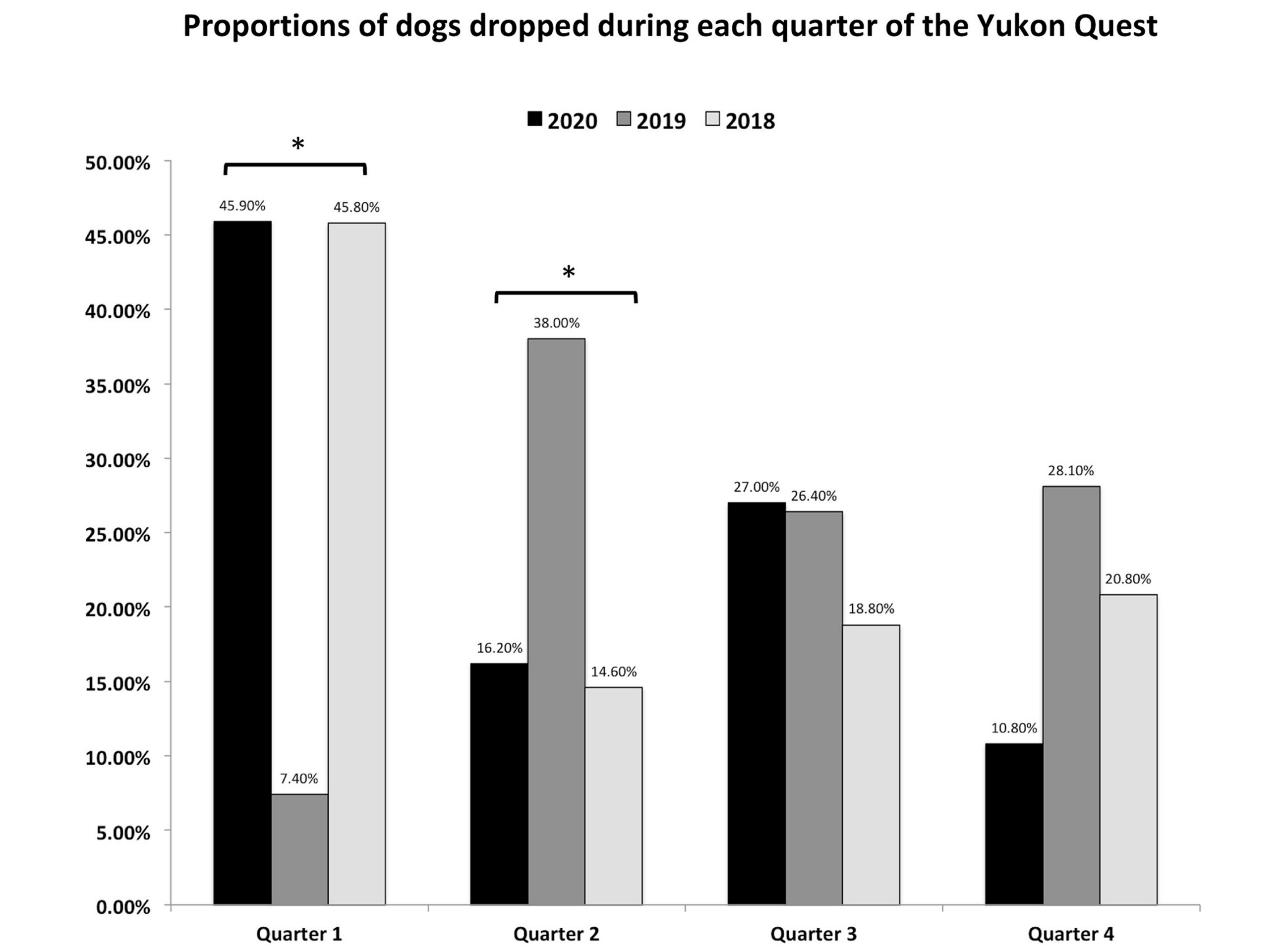

FIGURE 6
Proportions of dogs dropped during each quarter of the Yukon Quest. Note that the race alternates directions – starting in Fairbanks in even-numbered years and in Whitehorse in odd-numbered years. *Significant difference in proportions between groups ($p < 0.05$).

developed rhabdomyolysis between 2018 and 2020, one was from a team that would later go on to scratch, so only 1 of these dogs was included in the statistical analysis, and that dog was dropped from the race.

Our models examining individual injuries show that dogs with injuries to the carpus ($p = 2.6 \times 10^{-8}$), shoulder ($p < 2 \times 10^{-16}$), pectoralis ($p = 0.014$), or hindlimb ($p = 2.8 \times 10^{-9}$) were much more likely to be dropped. Antebrachial ($p = 0.29$), elbow ($p = 0.99$), metacarpal ($p = 0.63$), axial skeleton ($p = 0.98$), or dewclaw ($p = 0.99$) injuries did not make it more likely for a dog to be dropped.

Injury reoccurence

Thirty dogs that had an illness or injury went on to race a subsequent year. Five of those injuries reoccurred in the same location in four different dogs (13%). One dog had a reoccurring carpal injury, two dogs had a reoccurring shoulder injury, and one dog had both reoccur. Several of the dogs when dropped had multiple orthopedic localizations. In total, there were twenty-one carpal injuries and eleven shoulder injuries that did not reoccur. Dogs that experienced a hindlimb (4 dogs), pectoral (1 dog), dewclaw (1 dog), or other injury or illness (pneumonia, general soreness, cervical pain) did not experience it again.

Discussion

Canine athletes are dropped for varied reasons during the Yukon Quest International Sled Dog Race. Some mushers choose to drop dogs when they are not enjoying the race or are not pulling well ("slack-lining"). Or, dogs can be dropped due to injury or illness.

The most common injuries incurred while racing are orthopedic. Unsurprisingly, dogs diagnosed with an orthopedic injury are less likely to finish a race than those without. However, not all orthopedic injuries are the same, and dogs have a good chance of recovering from and continuing a race if they experience a carpal injury. Therefore, timely and accurate diagnosis of lamemess by race veterinarians is paramount. Orthopedic injuries can be treated along the route with wraps, massage, heat and/or ice. However, the International Federation of Sleddog Sports bans the use of pain medications during competition and if needed the dog must be dropped (4).

Not only were orthopedic injuries very prevalent during our study period, they were consistently the most common reason for dropping a dog. This high prevalence of orthopedic injuries is also consistent with data from a previous study of multi-day ultraendurance sled dog racing (1). These combined data suggests that mushers should constantly assess their dogs' gait for changes and report any suspected lameness to race veterinarians so the athlete can be properly evaluated. Identifying orthopedic injuries early allows for treatment to be initiated and may help the overall prognosis of the injury and prevent the need to drop the dog from the race. Some orthopedic injuries can also be prevented with endurance training prior to the race which helps strengthen bones, muscles, and tendons and stiffens cartilage and ligaments (5).

Thoracic limb injuries accounted for the vast majority of orthopedic injuries which is similar to previously reported injury localization in sled dogs and canine agility dogs (1, 2, 6). This is likely because the thoracic limb holds 60% of the bodyweight and is mainly responsible for stabilization as well as turning and steering and some propulsion (7). Meanwhile, the pelvic limb is mainly responsible for thrust and power and only bears 40% of the weight. The purposes of the limbs predispose the thoracic limb to injuries more than the pelvic limb.

The majority of injuries occurred at a joint, mainly the shoulder and carpal joints. Interestingly, dogs that compete in canine agility also have an increase in shoulder injuries (20%) but do not experience frequent carpal injuries (6%) in contrast to the sled dogs (8). Agility dogs also experience significantly more vertebrae injuries (6). Joints are uniquely susceptible to injury because they are under repetitive stress during exercise because the repetitive movements during exercise not only stress the joint but also the muscles that cross the joints and the ligaments needed for stabilization. Therefore, during a long endurance race such as the Yukon Quest the joints often are under great stress and can easily be injured. In addition, the joint is a common space for chronic disease processes such as osteoarthritis predisposing it to injuries during the race. Conditioning and training sporting dogs may help to prevent joint injuries, strengthen their muscles, and quicken athlete recovery if they do get injured (5). It is essential that dogs endurance train as well as strength train their muscles so that they are able to withstand long periods of exercise where they have to pull a sled. Most mushers condition their dogs by slowing increasing the mileage throughout the season which coincides with their race distances which often also get longer throughout the season. Conditioning also has physiologic effects such as decreasing resting heart rate, decreasing resting blood pressure, and increasing vascualization of the muscles allowing for more oxygen delivery (5). It is also important to note that too much conditioning may increase the likelihood of going into the race with a preexisting injury.

The brachial muscles (triceps brachii and biceps bracii) were included in our "shoulder" category since the race veterinarians in the field without diagnostic equipment are often unable to localize pain to a specific muscle, or do not record that specific information in the vet book. These muscles have an essential role in propelling the thoracic limb forward and supporting the limb during the weight bearing phase. The brachial muscles are therefore a crucial muscle group for movement. One study ultrasounded the shoulders of both dogs with shoulder pain and those without. Over 80% of the dogs ultrasounded had an abnormal finding. No correlation was found between clinical signs and abnormal ultrasound findings (9). In addition, there was a wide variety of shoulder abduction angles even in normal joints and fluid around the biceps tendon could not be related to pain in the shoulder. Therefore, in this study, ultrasound was unable to localize pain to a specific type of shoulder injury.

As noted in the results, the number of orthopedic injuries; specifically carpal injuries and "other" injuries sustained by dogs during the race was significantly different between years, but not their probability of being dropped once injured. This suggests that trail conditions, weather, etc. may impact the types of injuries that occur from year-to-year, but not the outcome of those injuries.

Our results are significant because they can help mushers and veterinarians decide whether a dog, based on the localization of the orthopedic injury, is statistically likely to finish, which may aid in decision-making regarding whether or not to drop a dog.

Carpal injuries were the most prevalent orthopedic injury followed by brachium and shoulder injuries. One hundred and forty-seven dogs experienced a carpal injury during the race and half of those athletes finished the race. In other words, 84% of athletes that finished with an orthopedic injury have a carpal injury. Meanwhile, only 11% of dogs that have a shoulder injury finished. This data indicates that an athlete with a carpal injury is more likely to respond to the treatment allowed during the race and be able to finish, compared to a dog with another orthopedic injury such as a shoulder or brachium injury localization. Based on this data, a dog experiencing an orthopedic injury other than a carpal injury is statistically unlikely to finish and a dog with a carpal injury has a 55% chance of finishing the race. This data allows veterinarians to give more informed recommendations to mushers about what types of orthopedic injuries should warrant dropping the dog from the race for recovery.

Cardiorespiratory disease also occurs on the trail, but can be difficult to properly diagnose without diagnostic equipment like ECGs, radiographs, and ultrasound available on the trail. Many trained sled dogs have "athletic heart syndrome," which is a physiologic hypertrophy of the heart that leads to increased flow velocity through the aortic valve and a grade I-II/VI systolic murmur (10). As such, trail veterinarians need to be able to distinguish the physiologic heart murmurs that occur in many trained sled dogs from pathologic cardiac disease. Sometimes sudden cardiac deaths do occur on the trail (though they are often a diagnosis of exclusion – 10). Pneumonia has also been reported, and aspiration pneumonia is a leading cause of sudden death in sled dogs (11). We did document that 11 dogs were dropped from the Yukon Quest with cardiorespiratory illness in the 3 years studied, no dogs died from these causes. We also identified that being diagnosed with a cardiorespiratory abnormality makes it much more likely for a dog to be dropped from the Yukon Quest.

Another condition that mushers have to be aware of is exertional rhabdomyolysis (a.k.a. sled dog myopathy), which is another historical leading cause of death during dog sled races (12). Rhabdomyolysis is a serious condition that is caused by rapid muscle breakdown that occurs during high intensity exercise. This breakdown releases myoglobin into the bloodstream that travels to the kidneys for excretion and can lead to visible myoglobinuria (pigmenturia). Intuitively, and according to the human literature, rhabdomyolysis causes a marked hyperkalemia (13), as potassium is released from disintegrated skeletal muscle cells into the plasma. This can cause cardiac arrhythmias and sudden death. However, a study performed during the 2015 Yukon Quest found that canines with rhabdomyolysis experienced hypokalemia (12). Regardless, these clinical syndromes require significant and immediate veterinary care for the best clinical outcome. In addition, sometimes the myoglobin froms myoglobin casts that are large enough to obstruct renal tubular epithelial cells and can lead to an acute kidney injury in the longer term (after the race has finished), and these dogs are lost to follow-up (11). In 2015, 5 cases of rhabdomyolysis were diagnosed on the trail of the Yukon Quest (12), and the corresponding author remembers years on the Yukon Quest trail (prior to 2018, and not including 2015) with numerous cases of rhabdomyolysis. However, in the 3 years of data analyzed for this study, only 2 cases were documented, both were dropped from the race; neither dog died. The cause of rhabdomyolysis is still unknown, but it likely has some correlation with improper conditioning (e.g., not enough training miles or simulated races) leading up to a race (12).

Gastrointestinal illness and/or inappetence sometimes occur during the ultramarathon sled dog races and can be due to either stress or enteric infectious disease. In human medicine, ischemic colitis is recognized as a common cause of GI distress during endurance running (14, 15). Dogs undergoing short bouts of extreme exercise (up to 30 miles) have been shown to maintain visceral blood flow (16), but it is unknown whether visceral blood flow is maintained over many days of ultramarathon racing where dogs are averaging more than 100 miles per day. In addition, both *Salmonella* and *Clostridium* species numbers have been documented to increase in the feces of dogs during races, however they were present in both dogs that experienced diarrhea and those who did not and therefore they cannot be implicated as the cause of disease (17). There are anecdotal reports that during warm weather, dogs are more likely to have a viral or bacterial outbreak that causes diarrhea; and warm/spoiled food or drop bags are sometimes implicated. We showed that being diagnosed with a gastrointestinal abnormality (most commonly diarrhea) did not increase the likelihood that a dog will be dropped from the Yukon Quest. In fact, as our data shows, many dogs diagnosed with diarrhea early in the race experience resolution of it and go on to finish in good health.

We examined whether any demographic factor (breed, sex, age) increased the likelihood of a dog being dropped from the Yukon Quest, in addition to injury and illness. We found that Siberian Huskies are less likely to be dropped from the Yukon Quest as well as are less likely to develop injury than Alaskan huskies. The Siberian Husky is an AKC registered breed with ancient roots that has historically been used to pull sleds. The Alaskan husky is not an AKC recognized breed and has genetics from other breeds in it's recent history. Most modern long distance race teams are made of the smaller, leaner, faster Alaskan huskies. It may be that Siberian Huskies are less likely to be dropped from races because they tend to run at slower speeds, are larger bodied, or have genetics that protect them from injury/illness on the trail. In addition, in this study only a select few number of mushers had teams with Siberian Huskies and they always made up the whole team. The way that these specific mushers cared for their dogs may also have contributed to the Siberian Huskies having a lower likelihood of being dropped during the race.

While the data stated can be generalized to other endurance sled dog races, there are some unique obstacles during the Yukon Quest trail such as the race direction as well as the trail conditions. Since the Yukon Quest changes direction in odd- and even- numbered years, we cannot compare checkpoints year-to-year. However, we divided the race into quarters to determine where along the race more dogs are dropped. We determined that when the race starts in Fairbanks, more dogs are dropped early, in the first quarter of the race. This makes sense, as the most notorious sections of trail (Eagle Summit) occurs during that section – Eagle Summit has steep elevation grades and is subject to blizzard conditions often during the race. It may be likely that mushers with inexperienced dogs are likely to drop them during this section of race. When the race starts in Whitehorse, Eagle Summit is later in the race, and those inexperienced dogs may have been dropped anywhere prior in the race, without that early pressure to do so. The dogs that make it to Eagle Summit in odd years are likely seasoned veterans and are less likely to be dropped. In odd-numbered years, more dogs are likely to be dropped in the second quarter of the race, which includes the longest unsupported stretch of trail (Pelly-Crossing to Dawson City – 210 miles). Similarly, mushers may feel compelled to leave inexperienced or young dogs behind prior to starting this long remote stretch of trail.

The Yukon Quest trail, weather, and musher decisions also play a role in the race. The trail often requires teams to make sharp turns and change direction to stay on course, which may predispose dogs to orthopedic injuries. In addition, some years there may be more ice on the course that causes slipping and prevents the dogs from gaining traction during the tight turns. Sometimes during the race, teams face snow storms and a large snow fall may cover the groomed trail. In this case, the dogs may steer away from the trail and punch through deep snow, causing a thoracic limb injury. Anecdotally, some mushers report that not using necklines reduces the incidence of front end injuries. The individual choices of the musher can also make a team more or less susceptible to injuries. The trail and weather conditions as well as the judgement of the musher are all factors that influence whether a dog will be dropped from the race. The data and conclusions that we provide in this paper not only add to the body of knowledge about sport dogs, injuries, and predisposing factors, but also will help guide mushers and race veterinarians in their decision making during races.

Future directions

The database created from this research is filled with valuable information. One future direction that we would like to explore is how weather during the race can impact the prevalence of orthopedic injuries and the localizations of those injuries. The type of snow, fresh or packed, may also have an impact on the types of injuries seen in athletes. Weather may also impact the prevalence of GI disease as some pathogens thrive at warmer temperatures and others may be more easily transmitted when the dogs are in closer proximity when it's cold.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: This dataset comes from veterinary medical record data that is not public. Requests to access these datasets should be directed to CH, cmhansen@alaska.edu.

Author contributions

JH: Data curation, Investigation, Writing – original draft, Writing – review & editing. MD: Formal analysis, Methodology, Writing – review & editing. CH: Conceptualization, Formal analysis, Methodology, Supervision, Visualization, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. Student funding was provided by the College of Veterinary Medicine and Biomedical Sciences at Colorado State University.

Acknowledgments

The authors would like to thank the Yukon Quest International for providing access to veterinary medical records, and Shawn Crimmins for assistance with the statistics.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Von Pfeil DJF, Liska WD, Nelson S, Mann S, Wakshlag JJ. A survey on orthopedic injuries during a marathon sled dog race. *Vet Med*. (2015) 6:329–39. doi: 10.2147/VMRR.S88276

2. Long RD. Treatment of common injuries in endurance racing sled dogs. *Compend Contin Educ Pract Vet*. (1993) 15:434–7.

3. R Core Team (2022). R: A language and environment for statistical computing. *R Fundation for Statistical Computing, Vienna, Austria*. Available at: https://www.R-project.org/

4. *Prohibited methods and substances for dogs [webpage on the internet]*. International Federation of Sleddog Sports. Available at: https://sleddogsport.net/eng/88 (Accessed March 25, 2022).

5. Marcellin-Little DJ, Levine D, Taylor R. Rehabilitation and conditioning of sporting dogs. *Vet Clin North Am Small Anim Pract*. (2005) 35:1427–39. doi: 10.1016/j.cvsm.2005.08.002

6. Cullen KL, Dickey JP, Bent LR, Thomason JJ, Moëns NM. Internet-based survey of the nature and perceived causes of injury to dogs participating in agility training and competition events. *J Am Vet Med Assoc*. (2013) 243:1010–8. doi: 10.2460/javma.243.7.1010

7. Zink C, Schlehr MR. Working dog structure: evaluation and relationship to function. *Front Vet Sci*. (2020) 7:7. doi: 10.3389/fvets.2020.559055

8. Levy M, Hall C, Trentacosta N, Percival M. A preliminary retrospective survey of injuries occurring in dogs participating in canine agility. *Vet Comp Orthop Traumatol*. (2009) 22:321–4. doi: 10.3415/VCOT-08-09-0089

9. Von Pfeil DJF, Davis MS, Liska WD, George C, Secrest S. Orthopedic and ultrasonographic examination findings in 128 shoulders of 64 ultra-endurance Alaskan sled dogs. *Vet Surg*. (2021) 50:794–806. doi: 10.1111/vsu.13621

10. Constable PD, Hinchcliff KW, Olson J, Hamlin RL. Athletic heart syndrome in dogs competing in a long-distance sled race. *J Appl Physiol*. (1994) 76:433–8. doi: 10.1152/jappl.1994.76.1.433

11. Dennis MM, Nelson SN, Cantor GH, Mosier DA, Blake JE, Basaraba RJ. Assessment of necropsy findings in sled dogs that died during Iditarod Trail sled dog races: 23 cases (1994–2006). *J Am Vet Med Assoc*. (2008) 232:564–73. doi: 10.2460/javma.232.4.564

12. Frye CW, Mann S, Joseph JL, Hansen C, Sass B, Wakshlag JJ. Serum biochemistry and inflammatory cytokines in racing endurance sled dogs with and without rhabdomyolysis. *Front Vet Sci*. (2018) 5:145. doi: 10.3389/fvets.2018.00145

13. Vanholder R, Sever MS, Erek E, Lameire N. Rhabdomyolysis. *J Am Soc Nephrol*. (2000) 11:1553–61. doi: 10.1681/ASN.V1181553

14. Oliveira EP, Burini RC, Jeukendrup A. Gastrointestinal complaints during exercise: prevalence, etiology, and nutritional recommendations. *Sports Med*. (2014) 44 Suppl 1:S79–85. doi: 10.1007/s40279-014-0153-2

15. Sanchez LD, Tracy JA, Berkoff D, Pedrosa I. Ischemic colitis in marathon runners: a case-based review. *J Emerg Med*. (2006) 30:321–6. doi: 10.1016/j.jemermed.2005.05.021

16. Van Citters RL, Franklin DL. Cardiovascular performance of Alaska sled dogs during exercise. *Circ Res*. (1969) 24:33–42. doi: 10.1161/01.RES.24.1.33

17. McKenzie E, Riehl J, Banse H, Kass PH, Nelson S Jr, Marks SL. Prevalence of diarrhea and Enteropathogens in racing sled dogs. *J Vet Intern Med*. (2010) 24:97–103. doi: 10.1111/j.1939-1676.2009.0418.x

Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 15 May 2024
DOI 10.3389/fvets.2024.1388470

Check for updates

OPEN ACCESS

EDITED BY
David Levine,
University of Tennessee at Chattanooga,
United States

REVIEWED BY
Bruno C. Menarim,
University of Kentucky, United States
Jane Manfredi,
Michigan State University, United States

*CORRESPONDENCE
Lauren V. Schnabel
✉ lvschnab@ncsu.edu
Katarzyna Dembek
✉ kdembek@ncsu.edu

RECEIVED 19 February 2024
ACCEPTED 01 May 2024
PUBLISHED 15 May 2024

CITATION
Hallowell KL, Dembek K, Horne CR, Knych HK, Messenger KM and Schnabel LV (2024) Systemic absorption of triamcinolone acetonide is increased from intrasynovial versus extrasynovial sites and induces hyperglycemia, hyperinsulinemia, and suppression of the hypothalamic-pituitary-adrenal axis. *Front. Vet. Sci.* 11:1388470. doi: 10.3389/fvets.2024.1388470

Systemic absorption of triamcinolone acetonide is increased from intrasynovial versus extrasynovial sites and induces hyperglycemia, hyperinsulinemia, and suppression of the hypothalamic-pituitary-adrenal axis

Kimberly L. Hallowell[1], Katarzyna Dembek[1*], Caitlyn R. Horne[1], Heather K. Knych[2], Kristen M. Messenger[3,4] and Lauren V. Schnabel[1,4*]

[1]Department of Clinical Sciences, College of Veterinary Medicine, North Carolina State University, Raleigh, NC, United States, [2]K. L. Maddy Equine Analytical Pharmacology Laboratory, School of Veterinary Medicine, University of California-Davis, Davis, CA, United States, [3]Department of Molecular Biomedical Sciences, College of Veterinary Medicine, North Carolina State University, Raleigh, NC, United States, [4]Comparative Medicine Institute, North Carolina State University, Raleigh, NC, United States

Steroid-associated laminitis remains a major concern with use of corticosteroids in horses. Individual case factors such as joint pathology, pre-existing endocrinopathies, or corticosteroid type, dose, and timing influencing steroid-induced laminitis risk have not been investigated. This study aimed to determine if systemic absorption of triamcinolone acetonide (TA) varies between intrasynovial (antebrachiocarpal) and extrasynovial (sacroiliac) injection sites, and to determine the effects of TA absorption on glucose, insulin, cortisol, and adrenocorticotropic hormone (ACTH). Twenty adult horses were randomized into antebrachiocarpal or sacroiliac joint injection groups, and each horse received bilateral injections with a total dose of 18 mg triamcinolone. Blood was collected prior to injection and at 1, 2, 4, 6, 8, 10, 12, 16, 20, 24, 36, 48, 60, and 72 h post-injection. Peak TA absorption occurred at 8 h in both groups, and was significantly higher in the intrasynovial group compared to the extrasynovial group (1.397 ng/mL, 0.672 ng/mL, $p < 0.05$). Plasma TA levels were significantly higher in the intrasynovial group from 8 to 36 h post-injection ($p < 0.05$). There was no difference in glucose, insulin, cortisol, or ACTH between groups at any time point. Insulin and glucose were significantly increased from baseline at all timepoints from 10–72 h and 1–72 h post-injection, respectively. Horses with elevated baseline insulin values (>20 μU/mL) from both groups experienced a more marked hyperinsulinemia, reaching a mean peak insulin of 197.5 μU/mL as compared to 90.06 μU/mL in those with normal baseline insulin. Cortisol and ACTH were significantly decreased from baseline at timepoints from 4–72 h post-injection in both groups. This study is the first to evaluate drug absorption from the sacroiliac site and demonstrates that drug absorption varies between intrasynovial and extrasynovial injection sites. TA absorption causes metabolic derangements, most notably a marked hyperinsulinemia that is more severe in horses with elevated baseline insulin values. The influence of baseline endocrinopathies on response to corticosteroid administration as well as the effect of corticosteroid-induced metabolic derangements warrant further investigation as risk factors for corticosteroid-associated laminitis.

KEYWORDS

corticosteroids, triamcinolone, insulin, cortisol, sacroiliac, horse

1 Introduction

Laminitis remains a major cause of animal suffering, economic loss, and emotional distress to owners and veterinarians. Laminitis is typically divided into three major categories: support-limb or mechanical laminitis, laminitis of inflammatory disease, and endocrinopathic laminitis. Of these three categories, endocrinopathic laminitis is the most common (1). Corticosteroid-associated laminitis is often discussed separately from the three primary categories, and evidence for the existence of corticosteroid-associated laminitis is lacking in the literature (2–7). Nevertheless, anecdotal reports and the authors' clinical experience indicate that one-time administration of corticosteroids at an accepted "safe" dose can be sufficient to induce laminitis in certain patients. Recent literature has shown that treatment with corticosteroids such as triamcinolone acetonide (TA) can induce cortisol suppression, hyperglycemia, and hyperinsulinemia in equine patients. Hyperglycemia and hyperinsulinemia persist for up to 72 h, and cortisol suppression persists for 11 days with intra-articular triamcinolone and greater than 15 days with intramuscular triamcinolone (8–10). Hyperinsulinemia has become a focus of research into endocrinopathic laminitis and seems to be a driving risk factor for development of disease (11–13). In the most recent Recommendations for the Diagnosis and Management of Equine Metabolic Syndrome published by the Equine Endocrinology Group it is suggested that corticosteroid-induced hyperinsulinemia may increase risk of laminitis and that screening for insulin dysregulation prior to corticosteroid administration is warranted (14). Further research into the metabolic effects of steroid administration, particularly alterations in insulin production and sensitivity, may provide a better understanding of the pathophysiology of steroid-induced laminitis and in turn allow for prevention of disease.

In a recent study examining laminitis risk in horses receiving joint therapy with triamcinolone, extrasynovial sites such as the sacroiliac joint were specifically excluded (6), and previous studies have not separated horses by site of injection (3, 5, 6). The pharmacokinetic and pharmacodynamic properties of intrasynovial triamcinolone have been established, but only following administration in the antebrachiocarpal joint (8, 9, 15). The sacroiliac joint is unique when compared to other joint injection sites in that the injection is performed outside of a synovial compartment and without direct visualization of the joint itself (16–18). To our knowledge, no previous studies have evaluated the drug absorption properties of extrasynovial sites such as the sacroiliac joint.

To begin to understand the individual case factors that put horses at risk for steroid-induced laminitis, this study aimed to evaluate variations in triamcinolone absorption when injected at an extrasynovial site (sacroiliac joint) as compared to an intrasynovial site (antebrachiocarpal joint), and to determine the effects of systemic TA absorption on glucose, insulin, cortisol, and adrenocorticotrophic hormone (ACTH) levels. We hypothesized that there would be increased systemic triamcinolone absorption from extrasynovial sites as compared to intrasynovial sites, and that triamcinolone administration would result in increases in glucose and insulin and suppression of cortisol and ACTH concentrations.

2 Materials and methods

2.1 Animal use and welfare

The study protocol was approved by the North Carolina State University Institutional Animal Care and Use Committee (Protocol #22-115). Twenty horses (14 mares, 5 geldings, and 1 stallion) from the university teaching herd ranging in age from 2 to 20 years old were enrolled. The horses had a mean ± standard deviation (SD) body weight of 525 ± 42.3 kg. Breeds included 13 Quarter Horse/Paints, 4 Thoroughbreds, 1 Standardbred, 1 Tennessee Walking Horse, and 1 Warmblood. All horses were determined to be healthy based on physical examination and had no history of corticosteroid administration for at least six months prior to the study period and no history of laminitis. Horses were not tested for endocrinopathies prior to enrollment in the study. Horses were randomly assigned to intrasynovial ($n = 10$) or extrasynovial ($n = 10$) injection groups. The mean ± standard deviation (SD) age of the intrasynovial group was 11.8 ± 5.7 years and the mean ± SD age of the extrasynovial group was 11.4 ± 5.7 years. The mean ± SD body weight of the intrasynovial group was 516.9 ± 45.7 kg and the mean ± SD body weight of the extrasynovial group was 532.1 ± 37.1 kg. Horses entered the study in cohorts of 4 and were acclimated to the research stalls and a no grain diet for five days prior to injection. Horses were offered grass hay and water *ad libitum* throughout the study period. Horses were monitored for any signs of adverse reaction to injections including daily physical examinations with evaluation of injection sites, soundness at a walk, and digital pulses.

2.2 Articular injections

Horses in the intrasynovial group (IS) were sedated with detomidine and horses in the extrasynovial group (ES) with detomidine and butorphanol to facilitate articular injections. The hair over the intended injection sites was clipped and the skin was aseptically prepared using chlorhexidine solution and 70% isopropyl alcohol. Both antebrachiocarpal joints were flexed and injected via the standard cranial approach with 9 mg of triamcinolone acetonide and 50 mg of amikacin for a total volume of 1.1 mL each site and a total systemic dose of 18 mg triamcinolone acetonide and 100 mg amikacin. Both sacroiliac joints were injected via the previously described cranial ultrasound-guided approach with 9 mg of triamcinolone acetonide and 50 mg of amikacin diluted to 10 mL with 0.9% NaCl at each site for a total systemic dose of 18 mg triamcinolone acetonide and 100 mg amikacin (17). Injections were performed between 7:00 AM and 7:30 AM for all horses.

2.3 Sample collection and processing

Blood was obtained by direct jugular venipuncture prior to injection and at 1, 2, 4, 6, 8, 10, 12, 16, 20, 24, 36, 48, 60, and 72 h post-injection. Whole blood from the collection syringe was used for stall-side glucose testing. The remaining blood was separated into red top and EDTA blood tubes and stored on ice until centrifugation at 3000 × g for 20 min at 4C. Serum and plasma were then transferred to cryovials and stored at −80°C until analysis.

2.4 Quantification of TA, glucose, insulin, cortisol, and ACTH

Plasma triamcinolone levels were determined by liquid chromatography-mass spectrophotometry as previously described by Knych et al. (15). Whole blood glucose levels were determined at time of sampling using an Accu-Check point-of-care reader on the dog setting. Plasma insulin levels were determined by enzyme-linked immunosorbent assay (07 M-60102, MP Biomedicals, LLC, Solon, Ohio). Serum cortisol levels were determined by coated-tube radioimmunoassay (0722110-CF, MP Biomedicals, LLC, Solon, Ohio). Plasma ACTH concentration was determined using an automated chemiluminescent assay (CLIA; ACTH Immulite 2000 kit, Siemens Medical Solutions USA, Tarrytown, New York). All assays were performed at the North Carolina State University and have been previously published for use in equids (19–22).

2.5 Statistical analysis

Data were tested for normality by a D'Agostino-Pearson test. Normally distributed data were reported as mean and SD. Non-normally distributed data were reported as median and interquartile range. Repeated measures 2-way ANOVA test was used to compare triamcinolone, insulin, glucose, cortisol, and ACTH concentrations over time from baseline and between 2 groups (IS and ES) at each time point. Dunnett's *post hoc* comparisons were made when relevant. Peak insulin concentration in horses with elevated and normal baseline insulin was compared with a *t*-test. Univariate logistic regression analysis was used to calculate the likelihood of peak insulin >100 uIU/mL in horses with elevated baseline insulin. The Hosmer and Lemeshow Goodness-of-Fit test indicated that the data fit the model ($p = 0.74$). Significance was set at $p < 0.05$. Statistical analysis was performed using Prism and IBM SPSS Statistical Software (SPSS and GraphPad Software, Inc., La Jolla, California).

3 Results

3.1 Physical examination parameters

No adverse reactions were noted and all horses had normal physical examination parameters throughout the study period. All horses tolerated repeated jugular venipuncture well with no changes in behavior or need for additional restraint.

3.2 Triamcinolone

Plasma triamcinolone levels for the IS versus ES group are displayed in Figure 1. TA levels were increased from baseline at all time points for both groups ($p < 0.05$). Plasma TA levels were greater in the IS group as compared to the ES group from 8 to 36 h post-injection ($p < 0.01$). Peak TA absorption occurred at 8 h post-injection in both groups and was significantly greater in the IS group than the ES group (1.61 ± 0.50 ng/mL vs. 0.70 ± 0.26 ng/mL, ($p < 0.01$)).

3.3 Glucose

Whole blood glucose values for the IS versus ES group are displayed in Figure 2A. Glucose values were increased from baseline at all time points for both groups ($p < 0.05$). There was no significant difference in glucose values between groups at any time point.

3.4 Insulin

Plasma insulin levels for the IS versus ES group are displayed in Figure 2B. Insulin levels for the IS group were increased from baseline at 10, 12, 16, 20, 24, and 60 h post-injection ($p < 0.05$). Insulin levels for the ES group were increased from baseline at 20, 24, 48, and 72 h post-injection ($p < 0.05$). There was no significant difference in insulin values between groups at any time point.

Plasma insulin values for horses with normal (<20 μU/mL) baseline values ($n = 9$; 4 from IS group and 5 from ES group) as compared to horses with elevated (>20 μU/mL) baseline values ($n = 11$; 6 from IS group and 5 from ES group) are displayed in Figure 3. Insulin levels for horses with elevated baseline insulin were higher at 0, 6, 12, 16, 20, 24, 36, 60, and 72 h post-injection compared to horses with normal baseline insulin ($p < 0.05$). Peak insulin values for horses in each group are displayed in Figure 4. Horses with elevated baseline insulin reached a peak insulin concentration of 197.5 ± 111.0 μU/mL which was higher than the peak insulin of 90.06 ± 26.92 μU/mL observed in the group with normal baseline insulin ($p < 0.05$).

Horses with elevated baseline insulin were 9 times more likely to reach peak insulin >100 uIU/mL post injections compared to horses with normal baseline insulin (OR = 9, 95% CI, 1.14–71).

3.5 Cortisol

Serum cortisol levels for the IS versus ES group are displayed in Figure 2C. Starting at 4 h post-injection and continuing until 72 h post-injection cortisol levels were decreased from baseline for both

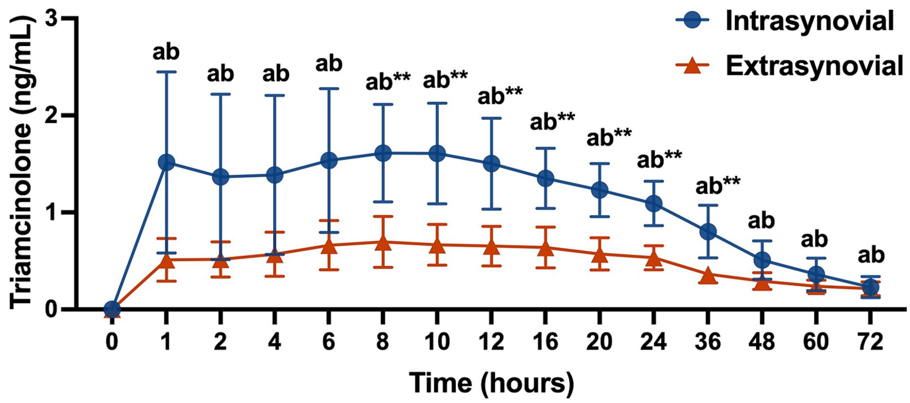

FIGURE 1
Plasma triamcinolone values (ng/mL) following intra- ($n = 10$) or extrasynovial ($n = 10$) injection with 18 mg triamcinolone acetonide. Data reported as mean and standard deviation for each group at all time points. Significant differences between groups are denoted by **($p < 0.01$) and from baseline for the intrasynovial group by the letter a ($p < 0.05$) and for the extrasynovial group by the letter b ($p < 0.05$) as determined by 2-way repeated measures ANOVA.

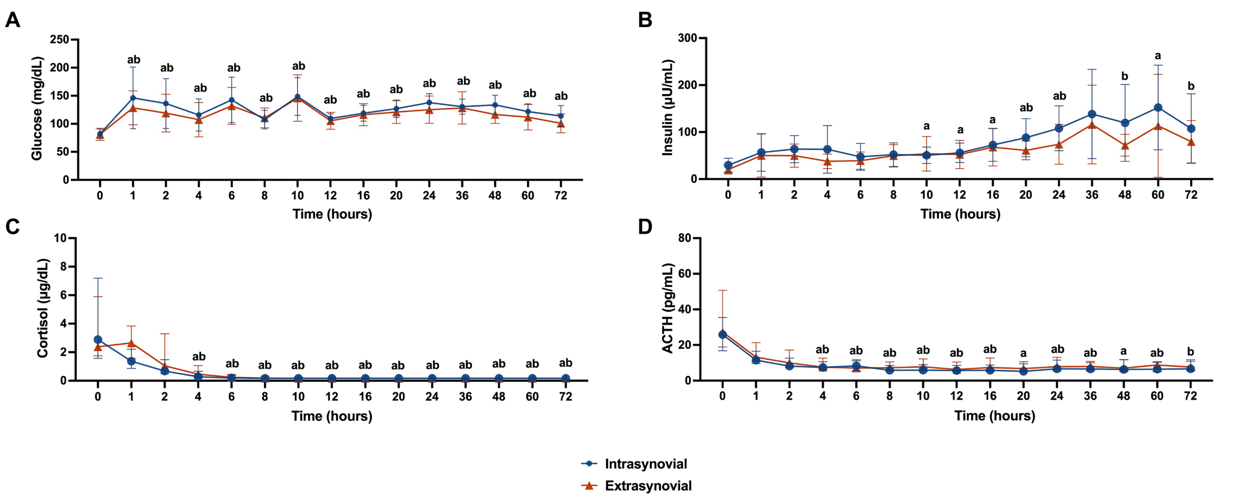

FIGURE 2
Metabolic parameters following intra- ($n = 10$) or extrasynovial ($n = 10$) injection with 18 mg triamcinolone acetonide. **(A)** Whole blood glucose (mg/dL), **(B)** plasma insulin (μU/mL), **(C)** serum cortisol (μg/dL), and **(D)** plasma ACTH (pg/mL). Normally distributed whole blood glucose and plasma insulin data reported as mean and standard deviation for each group at all time points. Non-normally distributed serum cortisol and plasma ACTH data reported as median and interquartile range for each group at all time points. Significant increases from baseline for the intrasynovial group are denoted by the letter a ($p < 0.05$) and for the extrasynovial group by the letter b ($p < 0.05$) as determined by 2-way repeated measures ANOVA. No significant differences were found between groups.

groups ($p < 0.05$). There was no significant difference in cortisol values between groups at any time point.

3.6 ACTH

Plasma ACTH levels for the IS versus ES group are displayed in Figure 2D. Starting at 4 h post-injection and continuing until 60 h post-injection ACTH levels were decreased from baseline for the IS group ($p < 0.05$). For the ES group, ACTH levels were decreased from baseline from 4 to 16 h post injection, and at 24, 36, 60, and 72 h post-injection ($p < 0.05$). There was no significant difference in ACTH values between groups at any time point.

4 Discussion

In this study we demonstrated differences in triamcinolone absorption between intra- and extrasynovial injection sites and added to the body of literature investigating the impact of corticosteroid administration on downstream metabolic parameters. This is the first study to evaluate drug absorption from the sacroiliac site, and the first to evaluate the impact of triamcinolone acetonide administration on ACTH levels.

Contrary to our hypothesis, plasma TA levels were significantly greater following intrasynovial injection than extrasynovial injection from 8–36 h post-injection. The peak plasma TA levels for the intrasynovial group (1.61 ng/mL) were similar to those previously

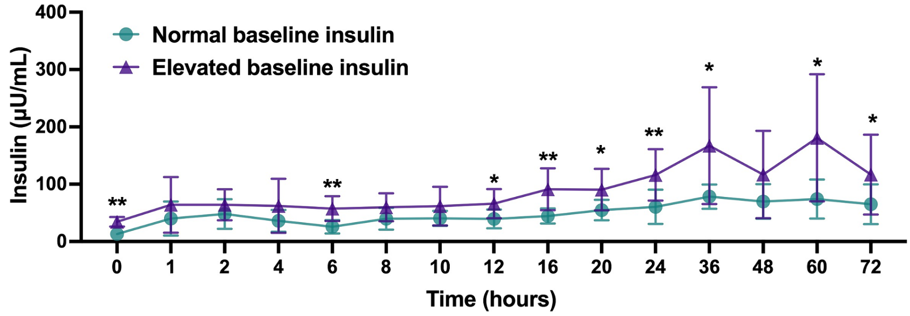

FIGURE 3
Plasma insulin (µU/mL) values following administration of 18 mg triamcinolone acetonide in horses with normal (<20 µU/mL, $n = 9$) or elevated (>20 µU/mL, $n = 11$) baseline insulin values. Data reported as mean and standard deviation for each group at all time points. Significant differences between groups are denoted by *($p < 0.05$) or **($p < 0.01$) as determined by 2-way repeated measures ANOVA.

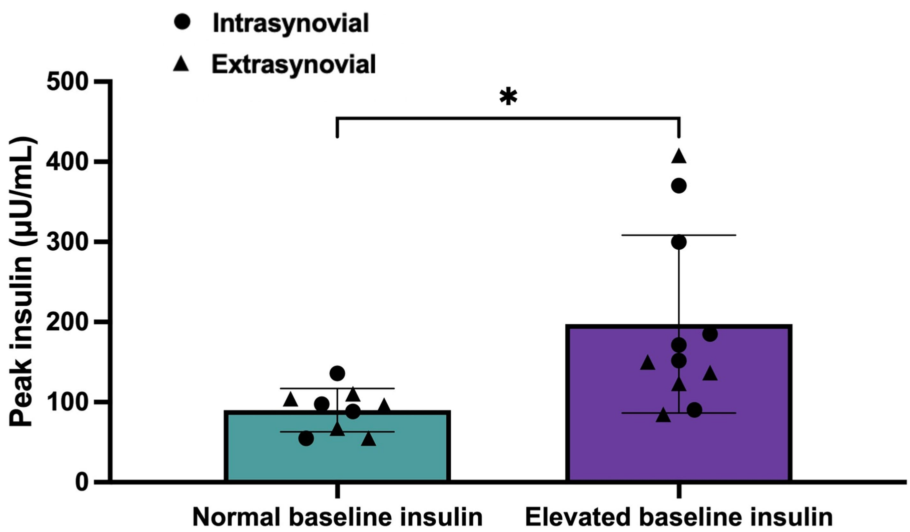

FIGURE 4
Peak plasma insulin (µU/mL) values following administration of 18 mg triamcinolone acetonide in horses with normal (<20 µU/mL, $n = 9$) or elevated (>20 µU/mL, $n = 11$) baseline insulin values. Peak values for each horse as well at the mean and standard deviation for each group are reported. Horses from the intrasynovial group are denoted by black circles and horses from the extrasynovial group are denoted by black triangles. t-test was used to determine significant difference as denoted by *($p < 0.05$) between groups.

reported by Soma et al. using a 0.04 mg/kg triamcinolone dose (0.94–2.5 ng/mL) (8). The peak TA levels for the extrasynovial group (0.70 ng/mL) were significantly lower than the intrasynovial group in this study, but higher than those reported for intramuscular administration (0.20–0.48 ng/mL) in the Soma study. This finding implies that the drug absorption properties of the sacroiliac joint injection site differ from both intrasynovial and intramuscular injection sites, which is reasonable given the nature of this extrasynovial injection close to the joint but also likely within the surrounding ligaments and muscle. A pharmacokinetic study evaluating absorption from extrasynovial injection sites would be beneficial in better understanding these findings.

Despite significant differences in triamcinolone absorption between groups, there was no significant difference in glucose, insulin, cortisol, or ACTH at any time point between groups and therefore the clinical relevance of this triamcinolone absorption finding is unclear. The degree of hyperglycemia seen in this study population was similar to that reported previously (9, 10). Glucocorticoids cause increased gluconeogenesis along with decreased tissue glucose uptake and relative insulin resistance, which is the likely mechanism for the hyperglycemia seen here (23, 24). Although the degree of hyperglycemia was mild from a clinical perspective, it may have contributed to subsequent hyperinsulinemia.

Horses in this study experienced significant hyperinsulinemia for up to 72 h post-injection. As sample collection was discontinued at the 72 h time point, the true duration of hyperinsulinemia for all horses could not be determined. The insulin response showed a high degree of individual variability with maximum insulin values ranging from 54.95 to 408.07 µU/mL. A large cohort study of ponies in England stratified ponies into low-, medium-, and high-risk groups for laminitis based on basal insulin levels. Ponies in the low-risk group (baseline insulin <21.6 µU/mL) had a 4 years cumulative incidence of laminitis of only 6%, while those in the high-risk group (baseline insulin >45.2 µU/mL) had an incidence of 69% (11). This modest degree of hyperinsulinemia was transiently present in all horses in the present study and persisted for at least 48 h in all but three horses. Sustained insulin levels of >208 μU/mL have been demonstrated to induce histopathologic evidence of laminitis in as little as 48 h (25). Three horses in this study achieved this degree of hyperinsulinemia, representing a group of horses that may be at increased risk for corticosteroid-associated laminitis. Although horses were not screened for endocrinopathies prior to inclusion in this study, all three of these horses did have elevated baseline insulin values (32.27 μU/mL, 47.70 μU/mL, 37.70 μU/mL). Despite this significant degree of hyperinsulinemia, no clinical signs of laminitis were observed in any horse. Radiographs or histopathologic evaluation of the laminae were not performed, but may have been able to detect laminitis that was not clinically evident.

The recent Boger et al. study evaluated the insulin and glucose response to the same dose of intrasynovial TA used presently, but only included horses with no evidence of insulin dysregulation as determined by an oral sugar test (10). Significant elevations in insulin were identified at 6, 24, and 48 h post-injection, but the mean peak insulin level was only 29 μU/mL as compared to the mean peak of 132.85 μU/mL found in our study population. The horses in the Boger study population had normal insulin response to an oral sugar test, while horses in our study population were not screened for insulin dysregulation prior to inclusion. In the subset of horses in our study population with elevated baseline insulin the mean peak insulin level was even higher at 197.5 μU/mL, while the mean peak insulin value for those with normal baseline insulin was only 90.06 μU/mL. Horses with elevated baseline insulin were nearly equally distributed between IS and ES groups and were 9 times more likely to reach a peak insulin of >100 μU/mL than those with normal baseline insulin. Baseline insulin is an insensitive measure of insulin dysregulation, so it is possible that a subset of horses with normal baseline insulin in our study population would have abnormal insulin responses to an oral sugar test. The presence of horses with insulin dysregulation undetected by baseline insulin abnormalities would explain the higher mean peak insulin value in our study population as compared to the Boger study population. Additionally, the use of an ELISA in our study versus a radioimmunoassay in the Boger study limits the ability to directly compare results. However, these findings argue that corticosteroids may induce more severe insulin dysregulation in horses with pre-existing baseline insulin dysregulation than those without, and that screening horses for insulin dysregulation may be an important step in mitigating risk of corticosteroid-associated laminitis. Further studies directly comparing the insulin response to corticosteroids in horses with diagnosed insulin dysregulation on the basis of an oral sugar test to those without are needed to confirm this finding.

Consistent with a previous study evaluating the impact of triamcinolone administration on endogenous hydrocortisone production, horses in this study experienced a significant decrease in cortisol levels from 4–72 h post-administration of triamcinolone. Additionally, a significant decrease in ACTH was present for the same time period. This is the first study to evaluate the ACTH response to triamcinolone administration, although previous studies have demonstrated ACTH suppression following administration of other corticosteroids (26, 27). These changes are indicative of suppression of the hypothalamic-pituitary-adrenal axis which may put patients at risk for secondary infections, and result in a clinical syndrome of ill-thrift, weight loss, and poor hair coat due to loss of normal cortisol functions (24). This risk should especially be considered in horses receiving repeated joint therapy with corticosteroids.

This study had several limitations, the first of which is that horses were unable to serve as their own controls due to the extended washout period that would be necessary before repeat assessment. Horses were also not screened for the presence of joint pathology, obesity, endocrinopathies, or laminitis prior to inclusion in the study, which may have affected drug absorption or the metabolic response to treatment. Additionally, horses in both groups were injected with amikacin combined with TA, and there was no TA only control. While there is no evidence in the current literature to suspect that amikacin could affect insulin levels or other metabolic parameters, it is unknown how this may have influenced study results. Horses were not evaluated for signs of laminitis with hoof testers or radiographs which may have allowed for detection of mild laminitis changes. A more prolonged sample collection period with more intensive monitoring may have been beneficial to determine the duration of metabolic changes and possible side effects that occur following triamcinolone administration. Finally, the use of an ELISA for insulin quantification limits the ability to directly compare the insulin values from our study population to others using the radioimmunoassay.

In conclusion, this study is the first to evaluate drug absorption from the sacroiliac site and demonstrated that systemic absorption of triamcinolone acetonide is greater from intrasynovial injection sites as compared to extrasynovial. The clinical relevance of this difference in absorption between sites is unclear as triamcinolone administration in horses in both groups resulted in hyperglycemia, hyperinsulinemia, and hypothalamic–pituitary–adrenal axis suppression up to 72 h post-injection. Hyperinsulinemia in some horses was profound and reached levels previously documented to increase risk for laminitis. There was a nearly equal distribution of horses with elevated baseline insulin between intrasynovial and extrasynovial groups and these horses had a significantly increased risk of developing marked hyperinsulinemia post-treatment. Further research is needed to determine if other corticosteroids and doses cause the same degree of metabolic derangements, and to determine the impact of these metabolic derangements on laminitis risk. Trends seen in this study indicate that screening for underlying insulin dysregulation may be an important tool in reducing risk of corticosteroid-associated laminitis, but additional studies are needed to confirm this finding.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was approved by North Carolina State University Institutional Animal Care and Use Committee (Protocol #22-115). The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

KH: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing, Software. KD: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing. CH: Conceptualization, Data curation, Investigation, Methodology, Resources, Supervision, Writing – review & editing. HK: Data curation, Formal analysis, Methodology, Resources, Writing – review & editing. KM: Conceptualization, Formal analysis, Methodology, Writing – review & editing. LS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This work was supported by the Foundation for the Horse Innovation and Discovery Grant and the North Carolina State University Department of Clinical Sciences VPP Resident Research Grant.

Acknowledgments

The authors would like to thank Ms. Jenna Schirmer for laboratory technical assistance and NCSU Laboratory Animal Resources staff for their help with animal care and handling.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

References

1. Karikoski NP, Horn I, McGowan TW, McGowan CM. The prevalence of endocrinopathic laminitis among horses presented for laminitis at a first-opinion/referral equine hospital. *Domest Anim Endocrinol*. (2011) 41:111–7. doi: 10.1016/j.domaniend.2011.05.004

2. Haseler CJ, Jarvis GE, McGovern KF. Intrasynovial triamcinolone treatment is not associated with incidence of acute laminitis. *Equine Vet J*. (2021) 53:895–901. doi: 10.1111/evj.13361

3. McCluskey MJ, Kavenagh PB. Clinical use of triamcinolone acetonide in the horse (205 cases) and the incidence of glucocorticoid-induced laminitis associated with its use. *Equine Vet Educ*. (2010) 16:86–9.

4. Bathe AP. The corticosteroid laminitis story: 3. The clinician's viewpoint. *Equine Vet J*. (2007) 39:12–3. doi: 10.2746/042516407X165801

5. Hammersley E, Duz M, Marshall JF. Triamcinolone administration does not increase overall risk of developing laminitis: abstracts. *Equine Vet J*. (2015) 47:24–4. doi: 10.1111/evj.12486_54

6. Potter K, Stevens K, Menzies-Gow N. Prevalence of and risk factors for acute laminitis in horses treated with corticosteroids. *Vet Rec*. (2019) 185:82–2. doi: 10.1136/vr.105378

7. Cornelisse CJ, Robinson NE. Glucocorticoid therapy and the risk of equine laminitis: glucocorticoid therapy and the risk of equine laminitis. *Equine Vet Educ*. (2013) 25:39–46. doi: 10.1111/j.2042-3292.2011.00320.x

8. Soma LR, Uboh CE, You Y, Guan F, Boston RC. Pharmacokinetics of intra-articular, intravenous, and intramuscular administration of triamcinolone acetonide and its effect on endogenous plasma hydrocortisone and cortisone concentrations in horses. *Am J Vet Res*. (2011) 72:1234–42. doi: 10.2460/ajvr.72.9.1234

9. French K, Pollitt CC, Pass MA. Pharmacokinetics and metabolic effects of triamcinolone acetonide and their possible relationships to glucocorticoid-induced laminitis in horses. *J Vet Pharmacol Ther*. (2000) 23:287–92. doi: 10.1046/j.1365-2885.2000.00288.x

10. Boger BL, Manfredi JM, Loucks AR, Salamey MZ, Kapeller LE, Fricano AG, et al. Intra-articular triamcinolone acetonide injection results in increases in systemic insulin and glucose concentrations in horses without insulin dysregulation. *Equine Vet J*. (2023) 56:326. doi: 10.1111/evj.14003

11. Knowles EJ, Elliott J, Harris PA, Chang Y, Menzies-Gow NJ. Predictors of laminitis development in a cohort of nonlaminitic ponies. *Equine Vet J*. (2022) 55:12. doi: 10.1111/evj.13572

12. De Laat MA, Reiche DB, Sillence MN, McGree JM. Incidence and risk factors for recurrence of endocrinopathic laminitis in horses. *J Vet Intern Med*. (2019) 33:1473–82. doi: 10.1111/jvim.15497

13. Tadros EM, Fowlie JG, Refsal KR, Marteniuk J, Schott HC. Association between hyperinsulinaemia and laminitis severity at the time of pituitary pars intermedia dysfunction diagnosis. *Equine Vet J*. (2019) 51:52–6. doi: 10.1111/evj.12963

14. Frank N, Bailey S, Bertin F, Burns T, de Laat M, Durham AE, et al. *Recommendations for the diagnosis and Management of Equine Metabolic Syndrome (EMS)* The Equine Endocrinology Group (2022).

15. Knych HK, Vidal MA, Casbeer HC, McKemie DS. Pharmacokinetics of triamcinolone acetonide following intramuscular and intra-articular administration to exercised thoroughbred horses: pharmacokinetics of triamcinolone in the horse. *Equine Vet J*. (2013) 45:715–20. doi: 10.1111/evj.12059

16. Cousty M, Rossier Y, David F. Ultrasound-guided periarticular injections of the sacroiliac region in horses: a cadaveric study. *Equine Vet J*. (2008) 40:160–6. doi: 10.2746/042516408X245252

17. Denoix JM, Jacquet S. Ultrasound-guided injections of the sacroiliac area in horses. *Equine Vet Educ.* (2008) 20:203–7. doi: 10.2746/095777308X292128

18. Engeli E, Haussler KK. Review of injection techniques targeting the sacroiliac region in horses: injection techniques targeting the sacroiliac region in horses. *Equine Vet Educ.* (2012) 24:529–41. doi: 10.1111/j.2042-3292.2011.00313.x

19. Rings LM, Swink JM, Dunbar LK, Burns TA, Toribio RE. Enteroinsular axis response to carbohydrates and fasting in healthy newborn foals. *J Vet Intern Med*. (2019) 33:2752–64. doi: 10.1111/jvim.15641

20. Hackett ES, McCue PM. Evaluation of a veterinary glucometer for use in horses: glucometer use in horses. *J Vet Intern Med*. (2010) 24:617–21. doi: 10.1111/j.1939-1676.2010.0481.x

21. Kinsella HM, Hostnik LD, Rings LM, Swink JM, Burns TA, Toribio RE. Glucagon, insulin, adrenocorticotropic hormone, and cortisol in response to carbohydrates and fasting in healthy neonatal foals. *J Vet Intern Med*. (2021) 35:550–9. doi: 10.1111/jvim.16024

22. Kinsella HM, Hostnik LD, Snyder HA, Mazur SE, Kamr AM, Burns TA, et al. Comparison of insulin sensitivity between healthy neonatal foals and horses using minimal model analysis. Fürnsinn C. *PLoS One*. (2022) 17:e0262584. doi: 10.1371/journal.pone.0262584

23. Harkins JD, Carney JM, Tobin T. Clinical use and characteristics of the corticosteroids. *Vet Clin North Am Equine Pract*. (1993) 9:543–62. doi: 10.1016/S0749-0739(17)30385-1

24. Cuming RS, Groover ES, Wooldridge AA, Caldwell FJ. Review of glucocorticoid therapy in horses. Part 1: pharmacology. *Equine Vet Educ.* (2018) 30:141–50. doi: 10.1111/eve.12555

25. De Laat MA, Sillence MN, McGowan CM, Pollitt CC. Continuous intravenous infusion of glucose induces endogenous hyperinsulinaemia and lamellar histopathology in standardbred horses. *Vet J*. (2012) 191:317–22. doi: 10.1016/j.tvjl.2011.07.007

26. Abraham G, Allersmeier M, Gottschalk J, Schusser GF, Hoppen H-O, Ungemach FR. Effects of dermal dexamethasone application on ACTH and both basal and ACTH-stimulated cortisol concentration in normal horses. *J Vet Pharmacol Ther*. (2009) 32:379–87. doi: 10.1111/j.1365-2885.2008.01054.x

27. Lavoie JP, Leclere M, Rodrigues N, Lemos KR, Bourzac C, Lefebvre-Lavoie J, et al. Efficacy of inhaled budesonide for the treatment of severe equine asthma. *Equine Vet J*. (2019) 51:401–7. doi: 10.1111/evj.13018

frontiers | Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 04 June 2024
DOI 10.3389/fvets.2024.1404331

OPEN ACCESS

EDITED BY
Heidi Reesink,
Cornell University, United States

REVIEWED BY
Andrea Bertuglia,
University of Turin, Italy
Brad Nelson,
Colorado State University, United States

*CORRESPONDENCE
Mounia Gruyaert
✉ mounia@equimove.be

RECEIVED 20 March 2024
ACCEPTED 15 May 2024
PUBLISHED 04 June 2024

CITATION
Gruyaert M, Oosterlinck M, Haspeslagh M and Nagy A (2024) Computed tomographic evaluation of the proximity of needles placed for perineural anesthesia of the palmar digital nerves to synovial structures in the foot: an *ex vivo* study.
Front. Vet. Sci. 11:1404331.
doi: 10.3389/fvets.2024.1404331

Computed tomographic evaluation of the proximity of needles placed for perineural anesthesia of the palmar digital nerves to synovial structures in the foot: an *ex vivo* study

Mounia Gruyaert[1]*, Maarten Oosterlinck[1], Maarten Haspeslagh[1] and Annamaria Nagy[2]

[1]Faculty of Veterinary Medicine, Department of Large Animal Surgery, Anaesthesia and Orthopaedics, Ghent University, Merelbeke, Belgium, [2]Equine Department and Clinic, University of Veterinary Medicine, Budapest, Hungary

Background: Potential synovial penetration following palmar digital nerve blocks has not been investigated.

Objectives: To evaluate the proximity of needles placed for palmar digital nerve blocks to nearby synovial structures using computed tomography (CT).

Study design: Descriptive observational study.

Methods: In 18 cadaver forelimbs, sequential injection of the navicular bursa (NB), distal interphalangeal joint (DIPJ) and digital flexor tendon sheath (DFTS) was performed using 3, 5 and 10 mL diluted radiodense contrast medium, respectively. After each synovial injection, 25 gage needles were placed over the palmar digital nerves at the proximal aspect of the ungular cartilages (distal injections) and 1 cm further proximally (proximal injections), and CT examination was performed. Subsequently, needles were removed, and the synovial structures further distended with the same volume as for the first injection. Perineural needle placement and image acquisition were repeated. The distance between the needle tip and adjacent synovial structures was measured (mm) in reconstructed images. Results were analyzed in separate general linear mixed models, to determine the effect of needle position and synovial distension on the distance from the tip of the needle to the NB, DFTS and DIPJ.

Results: Synovial penetration was confirmed following 12/420 (3%) needle placements (NB n = 5, 1 after proximal and 4 after distal injections; DIPJ n = 2, DFTS n = 2, NB or DIPJ n = 3, all after distal injections). The mean distance from the needle tip to the NB and DIPJ was significantly smaller after the second distension (NB: $p = 0.025$; DIPJ: $p < 0.001$) and with the distal needle placements (NB: $p < 0.001$; DIPJ: $p < 0.001$). For the DFTS, the distance from the needle tip was significantly smaller with the proximal needle placements ($p = 0.001$).

Main limitations: *Ex-vivo* study.

Conclusion: There is a small risk of synovial penetration when performing palmar digital nerve blocks, especially when distension of adjacent synovial structures is present.

KEYWORDS

equine, lameness, sports medicine, orthopaedics, synovial penetration, nerve block

Introduction

Perineural anesthesia of the palmar digital nerves is frequently used to localize lameness to the distal aspect of the limb. It is performed by depositing 1–1.5 mL local anesthetic solution at, or just proximal to the proximal margins of the ungular cartilages medially and laterally, using a 25 gage 16 mm needles (1–3).

Radiodense contrast medium has been widely used to study potential post-injection distribution characteristics of local anesthetic solution (4–8). Previous studies have shown inadvertent penetration of synovial structures following perineural injection, such as the carpometacarpal joint after perineural injection of the palmar metacarpal nerves (5), the digital flexor tendon sheath after perineural injection of the palmar and palmar metacarpal lateral and medial nerves (low 4-point nerve block) (4, 9, 10) and the tarsal sheath and tarsometatarsal joint following perineural injection of the deep branch of the lateral plantar nerve (7, 8). In situations with risk of inadvertent synovial penetration, antiseptic preparation prior to performing perineural anesthesia is strongly recommended (2, 3, 11).

There is anecdotal evidence of synovial fluid appearing in the needle hub when performing perineural anesthesia of the palmar digital nerve and iatrogenic synovial infection developing shortly following palmar digital nerve anesthesia has been reported (11, 12). However, to the authors' knowledge, there have been no published studies on the likelihood of complications following perineural anesthesia of the palmar digital nerves.

The objectives of this study were (a) to evaluate the proximity of needles placed for perineural anesthesia of the palmar digital nerves to nearby synovial structures navicular bursa (NB), distal interphalangeal joint (DIPJ), and the digital flexor tendon sheath (DFTS) using computed tomography (CT) and (b) to evaluate changes in the proximity of the needle tip with further distension of the synovial structures.

We hypothesized that inadvertent synovial penetration after perineural anesthesia of the palmar digital nerves can occur and that the needle tip would be closer to adjacent synovial structures (NB, DIPJ, and DFTS) with increased distension of the respective synovial structure.

Materials and methods

Eighteen cadaver forelimbs (nine left and nine right) from horses euthanised for reasons unrelated to this study were used. Clinical records of the horses were unknown. The limbs had been frozen for storage and were thawed 24 h prior to injections and image acquisition. The injection sites were clipped. Sequential injection of the NB, the DIPJ and the DFTS was performed using 3, 5 and 10 mL, respectively, of 1:1 diluted contrast medium (iohexol 240 mg/mL[1]) and tap water. The volumes were based on volumes routinely used for intrasynovial anesthesia (1, 13, 14). All injections and needle placements were performed by a single operator (resident of the European College of Sports Medicine and Rehabilitation; MG). The first injection performed on each limb was either into the NB or the DIPJ. The order of first injection was alternated between the NB and DIPJ (so each structure was injected first in 50% of the limbs). The DFTS was injected after the NB and DIPJ had been injected. Following each synovial injection, two 25 gage 16 mm needles were placed subcutaneously over the palmar digital nerves on the medial and lateral side. The needles were inserted just proximal to the palpable proximal edge of the medial and lateral ungular cartilages and were directed distally (1). A second needle was placed on both the medial and lateral sides, 1 cm proximal to the first insertion sites, also pointing distally. This was done mimicking a more proximal needle placements executed by some clinicians (14, 15). Following each synovial injection and perineural needle placement, a CT examination was performed. The needles over the palmar digital nerves were kept *in situ* for each CT examination, but were removed prior to any further synovial injection. When the subsequent synovial injection was deemed successful (based on synovial fluid appearing in the needle hub and/or contrast fluid being easily injected without any resistance), two 25 gage 16 mm needles were placed again as described above. The intrasynovial needles were kept *in situ* to allow subsequent injections (see later). To prevent leakage, a cap was attached to the needle hub. Subsequently, the same steps were repeated; each synovial structure was distended further with the previously used volume to mimic marked synovial distension. For the NB, a 19 gage 88 mm spinal needle was inserted in the midline between the heel bulbs immediately proximal to the coronary band, aiming halfway between the most dorsal and the most palmar aspects of the coronary band and 1 cm distal to the coronary band (1, 16). Correct needle placement was confirmed by a lateromedial radiograph. For the DIPJ injection, a 20 gage 38 mm needle was inserted perpendicular to the skin, 1 cm proximal to the coronary band, into the dorsal pouch of the DIPJ. The DFTS was injected using a 20 gage 38 mm needle, inserted at the axial border of the lateral proximal sesamoid bone (17). A CT examination was performed after each distension; each limb was scanned six times in total. A 16 slice multidetector fan beam CT (2) (Qalibra CT System, Canon Aquilion LB) was used. The images were acquired with a slice thickness of 0.5 mm (tube rotation time 0.5 s). The field of view was 320 mm and the images were generated at 350 mAs and 135 kV.

Images were analyzed using multiplanar reconstruction (MPR) and a bone algorithm in a medical image viewing software [JiveX (3)]. After assessment of different reconstructions, it was decided that the most suitable plane to measure the shortest distance between the tip of the needle and the synovial structures was the sagittal plane for the NB and DIP joint and the transverse plane for DFTS. In the sagittal plane, the reference lines were set parallel with the deep digital flexor tendon and perpendicular to this line. In the transverse plane, reference lines were set parallel with the palmar surface of the navicular bone and perpendicular to this line. All measurements were performed three times, and the shortest distance (mm) from the tip of the needle to the injected synovial structure was used for further analysis. Five categories were defined: 1. Penetration: inadvertent penetration of a synovial structure, confirmed by presence of contrast medium in the needle hub (Figures 1–3); 2. Adjacent: the needle tip was adjacent to the synovial structure but no contrast leakage was noted (Figure 4); 3. The needle tip was not adjacent but <5 mm from the synovial structure; 4. a distance of ≥5 mm but <10 mm between the needle tip and the synovial structure and 5. a distance of ≥10 mm between the needle tip and the synovial structure.

Two limbs with major tendon abnormalities (rupture of both superficial digital flexor tendon and deep digital flexor tendon) observed during CT evaluation were excluded from the study.

Data analysis

Statistical analysis was carried out in IBM SPSS Statistics 26.0 (4). Statistical significance was set at $p \leq 0.05$. Descriptive statistics were performed in spreadsheet software (Microsoft Excel version 16). To determine the effect of needle position and synovial distension on the distance from the tip of the needle to the NB, DFTS and DIPJ, a separate general linear mixed model was used for each synovial structure, with distance from the needle tip to the synovial structure as dependent variable, distension (first/s), needle position (proximal/distal) and their interaction as fixed effects, and limb and location within limb (lateral/medial) as random effects. Normality of residuals for these models was visually verified on QQ-plots and formally confirmed with a Kolmogorov–Smirnov test. If residuals could not be assumed to be normally distributed, the analysis was performed using generalized estimating equations with identity link function on rank-transformed data instead, with the lowest distance yielding the lowest rank (18). In the latter case, the presence of related measurements in the dataset was addressed by including limb and location within limb (lateral/medial) in the model as subject effects in an unstructured correlation matrix.

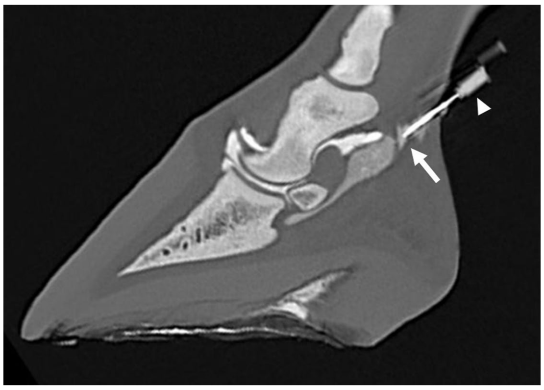

FIGURE 1
Parasagittal computed tomographic reconstruction, showing penetration of the navicular bursa (arrow) by a needle inserted just proximal to the ungular cartilage after the second distension of the navicular bursa with 3 mL of diluted contrast medium. Contrast leakage from the needle hub is clearly visible (arrowhead).

Results

In total, there were 420 needle placements over the palmar digital nerves, of which 204 were at the proximal and 216 at the distal injection site (in the first limb, proximal injections were not performed). Synovial penetration was confirmed following 12/420 (3%; 95% confidence interval [CI] 1.5–4.9%) needle placements (Table 1). In 11/12 (92%; 95% CI 61.5–99.8%) needle placements, this occurred after the second distension. Of the 12 synovial penetrations, 10 (83%; 95% CI 51.2–98.0%) occurred following distal needle placements.

Following 11/420 (3%; 95% CI 1.3–4.6%) needle placements, the tip of the needle was adjacent to a synovial structure, but no contrast leakage was seen (Supplementary item 1). In 7/11 limbs (64%), this was after the second distension (DIPJ $n=5$, DFTS $n=6$) and in 7/11 limbs (64%) with the proximal needle placement (DFTS $n=6$, DIPJ $n=1$, DIPJ $n=4$). In one limb, contrast was noted in the DIPJ after injection of the NB, indicating direct communication between the two structures. The results of the other categories are shown in Supplementary item 1.

Statistical analysis

Navicular bursa

The mean distance from the distal needle tip to the NB was significantly smaller ($p=0.025$) after the second than after the first distension (Table 2). The mean distance from the needle tip to the NB was significantly smaller with the distal than with the proximal needle placements ($p<0.001$). Four of five penetrations of the NB occurred after the second distension and all five were with distal needle placements (Table 1).

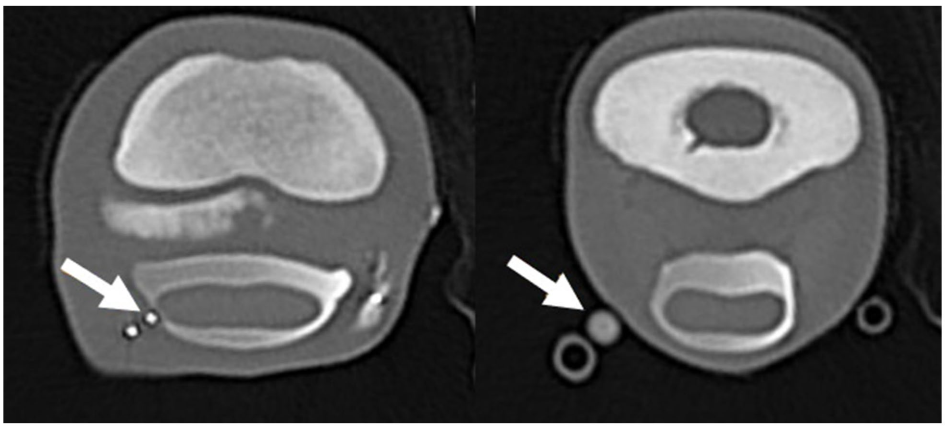

FIGURE 2
Transverse computed tomographic reconstruction, showing penetration of the digital flexor tendon sheath (DFTS) (arrow left image) and contrast leakage from the proximal (medial) needle (arrow right image) after the second distension with 10 mL diluted radiodense contrast medium. The arrow on the left image is showing the distal needle tip penetrating the DFTS; the right image is showing contrast leakage from the needle hub.

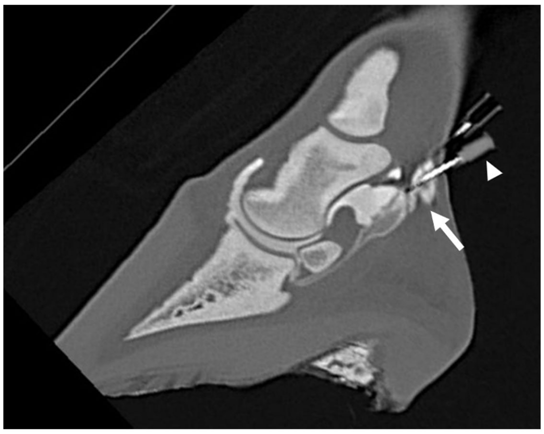

FIGURE 3
Parasagittal computed tomographic reconstruction, showing penetration (arrow) of either the navicular bursa or the distal interphalangeal joint by the distal needle after the second distension of the NB and DIPJ with 3 mL and 5 mL of diluted radiodense contrast medium, respectively. It was not possible to differentiate if the needle penetrated the NB or the DIPJ. Contrast leakage from the needle hub is visible (arrowhead).

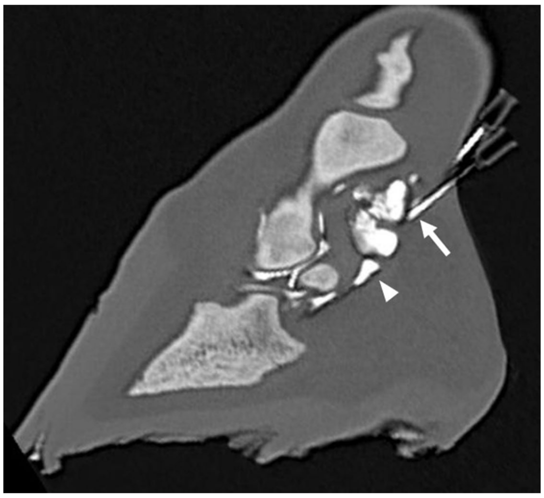

FIGURE 4
Parasagittal computed tomographic reconstruction, showing the distal needle adjacent to the distal interphalangeal joint (arrow) after a single distension with 5 mL diluted radiodense contrast medium. Note that the navicular bursa (arrowhead) has also been distended with contrast medium.

Distal interphalangeal joint

The mean distance from the needle tip to the DIPJ was significantly smaller ($p < 0.001$) after the second than after the first distension. The mean distance from the needle tip to the DIPJ was significantly smaller with the distal than with proximal needle placements ($p < 0.001$) (Table 2).

Following 115/140 (82.1%) needle placements, the distance from the needle tip was <5 mm away from the DIPJ. Six of seven penetrations and adjacent needle placements occurred with the distal needle placements (Supplementary item 1).

Digital flexor tendon sheath

No significant difference was noted between the median distance from the needle tip to the DFTS between first and the second distension. The distance from the needle tip the to the DFTS was significantly shorter with the proximal than with distalneedle placements ($p = 0.001$) (Table 2).

Following 98/140 (70.0%) needle placements, the distance from the needle tip was <5 mm from the DFTS. Six of eight penetrations and adjacent needle placements occurred after the second distension, all of which with the proximal needle placements (Supplementary item 1).

Discussion

This study is the first to perform a detailed evaluation of the proximity of needles placed for perineural anesthesia of the palmar digital nerves to synovial structures in the foot. In this study, we focused on the NB, DIPJ and DFTS because of their close relationship to the injection sites of perineural anesthesia of the palmar digital nerves. The NB, the palmaroproximal pouch of the DIPJ and the distal aspect of the DFTS are closely related, separated by the proximal sesamoidean ligament (also called T-ligament or transverse laminae) and the collateral sesamoidean ligament (19–21). The proximal sesamoidean ligament is loose connective tissue corresponding to the apposition of palmaroproximal recess of the DIPJ, the proximal recess of the NB and distal recess of the DFTS and lies in close relationship to the collateral sesamoidean ligament which originates on the medial and lateral aspect of the proximal phalanx and inserts on the proximal aspect of the navicular bone (21, 22). The proximal interphalangeal joint lies dorsal to the deep digital flexor tendon (and DFTS) and was therefore not investigated in this study (23).

In agreement with our hypotheses, synovial penetration occurred only after a small proportion of injections, and the distance from the needle tip to adjacent synovial structures was significantly smaller when the NB and the DIPJ had been distended twice. Also, the distance from the needle tip to adjacent synovial structures (NB and DIPJ) was significant smaller with the distal needle placements. The latter finding can be explained by the anatomical location of the NB (distal to the proximal ungular cartilages) and of the palmaroproximal pouch of the DIPJ. In contrast, the distance from the needle tip to the DFTS was significant smaller with proximal needle placements. This could be explained by the presence of the additional soft tissue coverage by the distal digital annular ligament in this region, which is not present more proximally (23).

Our results suggest that there is a small risk of synovial penetration when performing perineural anesthesia of the palmar digital nerves, at least for the NB and the DIPJ. As the perineural injections are performed near the proximal margin of the ungular cartilages, the direction and location of the needle placement in relation to the ungular cartilages could play a role (3, 24). In practice, some variations in execution of the perineural anesthesia of the palmar digital nerves among veterinarians exist. A first factor is the location of the needle placement in relation to the ungular cartilages. A slightly more proximal injection site in relation to the ungular cartilages can be used, but this increases the risk of proximal diffusion and potential desensitization of the pastern and distal fetlock region (16, 25). A second factor is the direction of the needle. In the current study, and

TABLE 1 The number of penetrations of the navicular bursa (NB), distal interphalangeal joint (DIPJ), and digital flexor tendon sheath (DFTS) following perineural needle placement over the palmar digital nerves.

	First distension		Second distension		TOTAL penetrations
	Proximal	Distal	Proximal	Distal	N
NB	0	1	0	4	5
DIPJ	0	0	0	2	2
NB/DIPJ	0	0	0	3	3
DFTS	0	0	2	0	2
TOTAL	0	1	2	9	12

The synovial structures were injected with 3 mL (NB), 5 mL (DIP), and 10 mL (DFTS) of 1:1 diluted contrast medium. After each injection ("First Distension") needles were inserted just proximal to the palpable edge of the medial and lateral ungular cartilages and were directed distally ("Distal"). The second needles were placed 1 cm proximal to the first insertion sites ("Proximal"). Subsequently, the same steps were repeated; each synovial structure was injected a second time with 3 mL (NB), 5 mL (DIP) and 10 mL (DFTS) of 1:1 diluted contrast medium to mimic marked synovial distension ("Second Distension").

TABLE 2 Distance from the distal needle tip to the navicular bursa (NB), distal interphalangeal joint (DIPJ), and digital flexor tendon sheath (DFTS).

	First Distension (mm)	Second Distension (mm)	*p*-value	Proximal needle placement (mm)	Distal needle placement (mm)	*p*-value
NB (mean ± sd)	18.5 ± 8.6	17.5 ± 8.8	0.025*	21.7 ± 7.8	14.4 ± 8.0	<0.001*
DIPJ (mean ± sd)	11.7 ± 5.3	9.1 ± 6.0	<0.001*	13.4 ± 5.5	7.5 ± 4.4	<0.001*
DFTS (median and range)	2.6 (0–14)	2.0 (0–12)	0.5	1.7 (0–6.1)	3.0 (0–13.9)	0.001*

Normally distributed data are shown as mean ± standard deviation (NB and DIPJ), whereas data not normally distributed are presented as median and range (DFTS). The synovial structures were injected with 3 mL (NB), 5 mL (DIP) and 10 mL (DFTS) of 1:1 diluted contrast medium. After each injection ("First Distension") needles were inserted just proximal to the palpable proximal edge of the medial and lateral ungular cartilages and were directed distally ("Distal"). The second needles were placed 1 cm proximal to the first insertion sites ("Proximal"). Subsequently, the same steps were repeated; each synovial structure was injected a second time with 3 mL (NB), 5 mL (DIP) and 10 mL (DFTS) of 1:1 diluted contrast medium to mimic marked synovial distension ("Second Distension"). *p*-values illustrate statistically significant ($p \leq 0.05$) differences between first and second distensions, and between proximal and distal needle placements.

as described in most reference texts, the needles were inserted subcutaneously in a proximal to distal direction, which results in the needle tip ending distally to the skin penetration site (1–3). For the NB and DIPJ, more penetrations occurred with the distal needle placements. As discussed earlier, this finding can be explained by the anatomical location of the NB and DIPJ. It could therefore be considered to direct the needle perpendicular to the skin, to avoid a more distal position of the needle tip. In combination with the use of a shorter 26 gage, 13 mm needle, it can be speculated that the distance to the nearby synovial structures could be decreased and therefore, the risk of inadvertent synovial penetration could be mitigated. Two of the authors routinely use this modification (26 gage, 13 mm needles in combination with needle insertion perpendicular to the skin) for perineural anesthesia of the distal digital nerves. However, for cob types and other horses with a thick skin, a 16 mm and ≤ 26 gage needles may be necessary. Further studies need to be performed to assess the effect of these modifications on the resulting distance of the needle tip to the adjacent synovial structures.

If synovial penetration occurs while performing perineural anesthesia of the palmar digital nerves, it is possible that the loss of local anesthetic solution into a synovial structure results in an incomplete desensitization of the nerve. Inadequate nerve desensitization can be detected by checking loss of skin sensitivity at the heel bulbs, although there is not a complete correlation between loss of skin sensitivity and resolution of lameness due to foot pain (2, 26).

Several previous *(ex vivo)* studies have shown potential inadvertent penetration of synovial structures such as the carpometacarpal joint, the DFTS, the tarsal sheath and tarsometatarsal joint following perineural injections (4, 5, 7–10). Two of these studies (7, 9) have investigated using different volumes at the injection sites, but no studies have distended the synovial structures prior to the perineural injection. In our study, penetration of a synovial structures occurred in 12/420 (3%) of needle placements and more frequently after the second distension, suggesting that inadvertent synovial penetration is more likely if adjacent synovial structures are markedly distended, at least for the NB and the DIPJ. Although based on published scientific literature and the authors' clinical experience, iatrogenic infections after performing perineural anesthesia in general, and of the palmar digital nerves specifically, are very rare, clinicians should be aware of the potential risk of inadvertent synovial penetration. Based on our study, this may be particularly relevant when there is a palpable distension of adjacent synovial structures. Therefore, thorough palpation of synovial structures should always be performed, although this is not possible for the NB due to its anatomical location. Theoretically, this could be visualized by ultrasonographic evaluation but this is not a practical approach prior to perineural anesthesia in a clinical setting. A potential explanation for the low incidence of iatrogenic synovial infection after perineural anesthesia may be that not every synovial penetration would necessarily result in synovial contamination and infection. Local anesthetics present antimicrobial activity against equine bacterial pathogens at concentrations that are used in practice (27).

In one limb, diffusion of the contrast medium from the NB to the DIPJ was noted. In one earlier study using CT arthrography, an occasional direct communication from the DIPJ to the NB was reported in 7/133 (5.3%) cadaver limbs (13). The authors stated that communication could occur through the proximal sesamoidean ligament or the distal sesamoidean impar ligament. The latter could be associated with the presence of a distal border fragment (13). This can be an important consideration in the context of intrasynovial anesthesia of the NB or DIPJ but is not directly relevant to our study.

This study had some limitations. This is an *ex-vivo* study on a relatively small number of limbs, and the distension induced during the first and second synovial injections might not reflect naturally occurring synovial distension. Any baseline distension prior to injection of contrast medium was not assessed. However, the experimental design of the study allowed studying the effect of a standardized mild and marked synovial distension, in combination with very detailed evaluation using cross-sectional CT imaging. Despite a single experienced operator performing all procedures using the same technique, a slight variation in the location and orientation of perineural needle placements between distensions might have occurred. The clinical history of the horses was not available but if major abnormalities were observed during the CT evaluation, limbs were excluded, and therefore, this is considered unlikely to have affected our results.

Further studies to better assess the potential risk of synovial penetration in clinical situations could include *in-vivo* studies by performing an injection with local anesthetic solution and/or radiodense contrast medium over the palmar digital nerves, followed by radiographic assessment of any contrast accumulation in nearby synovial structures (4, 5, 15). Alternatively, yet more complicated, it could be considered to measure the concentration of local anesthetic solution in nearby synovial structures (14).

In conclusion, inadvertent penetration of the DIPJ, NB or DFTS may occur when performing perineural anesthesia of the palmar digital nerves, although based on this *ex vivo* study, the risk seems very low. Nevertheless, clinicians should be aware of this potential risk and needle size and direction may warrant further consideration and research.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the studies involving animals in accordance with the local legislation and institutional requirements because the material used was derived from horses that were subject to euthanasia for unrelated reasons. Written informed consent was not obtained from the owners for the participation of their animals in this study because by signing the general consent form of the hospital on admission of all cases, owners agree for data acquired on their horses to be used for teaching and research purposes.

Author contributions

MG: Conceptualization, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. MO: Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. MH: Data curation, Formal analysis, Writing – original draft, Writing – review & editing. AN: Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

The authors are grateful to Gabriella Lukics for her help in computed tomographic image acquisition. The authors would like to thank the Equine Department and Clinic of the University of Veterinary Medicine Budapest for providing technical facilities and materials for this study free of charge.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2024.1404331/full#supplementary-material

References

1. Schumacher J, Schramme MC, DeGraves FJ, Smith R, Coker M. Diagnostic analgesia of the equine forefoot. *Eq Vet Educ.* (2004) 16:159–65. doi: 10.1111/j.2042-3292.2004.tb00288.x

2. Bassage LH II, Ross MW. Chapter 10: diagnostic analgesia In: MW Ross and SJ Dyson, editors. *Lameness in the horse*. *2nd* ed. St. Louis, MO: Saunders (2011)

3. Baxter GM, Stashak TS. Chapter 2: examination for lameness In: GM Baxter, editor. *Lameness in horses*. *7th* ed. Hoboken, NY: Wiley Blackwell (2020)

4. Nagy A, Bodo G, Dyson S, Compostella F, Barr ARS. Distribution of radiodense contrast medium after perineural injection of the palmar and palmar metacarpal nerves (low-4-point nerve block: an *in vivo* and *ex vivo* study in horses). *Equine Vet J.* (2010) 42:512–8. doi: 10.1111/j.2042-3306.2010.00076.x

5. Nagy A, Bodo G, Dyson S. Diffusion of contrast medium after four different injection techniques for analgesia of the proximal metacarpal region: an *in vivo* and *in vitro* study. *Equine Vet J.* (2012) 44:668–73. doi: 10.1111/j.2042-3306.2012.00564.x

6. Jordana M, Marten A, Duchateau L, Vanderperren K, Saunders J, Oosterlinck M, et al. Distal limb desensitisation following analgesia of the digital flexor tendon sheath in horses using four different techniques. *Equine Vet J.* (2013) 46:488–93. doi: 10.1111/evj.12186

7. Claunch KM, Eggleston RB, Baxter GM. Effects of approach and injection volume on diffusion of mepivacaine hydrochloride during local analgesia of the deep branch of the lateral plantar nerve in horse. *J Am Vet Med Assoc*. (2014) 245:1153–9. doi: 10.2460/javma.245.10.1153

8. Contino EK, King MR, Valdés-Martinez A, McIIWraight . In vivo diffusion characteristics following perineural injection of the deep branch of the lateral plantar nerve with mepivacaine or iohexol in horses. *Equine Vet J*. (2015) 47:230–4. doi: 10.1111/evj.12261

9. Seabaugh KA, Selberg KT, Valdés-Martinez A, Rae S, Baxter GM. Assessment of the tissue diffusion of anesthetic agent following administration of a low palmar nerve block in horses. *J Am Vet Med Assoc*. (2011) 239:1334–40. doi: 10.2460/javma.239.10.1334

10. de Souza AF, Pascual JC, Maia BT, De Zoppa AL. Diffusion of dye after perineural injection of the palmar/plantar nerves in two different sites in horses: an ex-vivo study. *Vet Res Commun*. (2022) 46:283–8. doi: 10.1007/s11259-021-09856-6

11. Schumacher J, Schramme MC, Schumacher J, DeGraves FJ. Diagnostic analgesia of the equine digit. *Equ Vet Educ*. (2013) 25:408–21. doi: 10.1111/eve.12001

12. Pilsworth R, Dyson S. Where does it hurt? Problems with interpretation of regional and intra-synovial diagnostic analgesia. *Eq. Vet. Edu.* (2015) 27:595–603. doi: 10.1111/eve.12392

13. Hontoir F, Rejas E, Falticeanu A, Nisolle J-F, Simon V, Nicaise C, et al. Communication between the distal interphalangeal joint and the navicular bursa in the horse at computed tomography arthrography. *Anat Histol Embryol*. (2019) 48:133–41. doi: 10.1111/ahe.12421

14. Gough M, Mayhew IG, Munroe GA. Diffusion of mepivacaine between adjacent synovial structures in the horse. Part 1: forelimb foot and carpus. *Equine Vet J*. (2002) 34:80–4. doi: 10.2746/042516402776181097

15. Schumacher J, Livesey L, Degraves FJ, Schumacher J, Schramme MC, Hatchcock J, et al. Effect of anaesthesia of the palmar digital nerves on proximal interphalangeal joint pain in the horse. *Equine Vet J*. (2004) 36:409–14. doi: 10.2746/0425164044868404

16. Nagy A, Malton R. Diffusion of radiodense contrast medium after perineural injection of the palmar digital nerves. *Eq Vet Educ*. (2015) 27:648–54. doi: 10.1111/eve.12369

17. Verschooten F, Desmet P, Peremans K, Picavet T. Navicular disease in the horse: the effect of controlled intrabursal corticosteroid injection. *J Equine Vet*. (1991) 11:316–20.

18. Hassel DM, Stover SM, Yarbrough TB, Drake CM, Taylor KT. Palmar-plantar axial sesamoidean approach to the digital flexor tendon sheath in horses. *J Am Med Vet*. (2000) 217:1343–7. doi: 10.2460/javma.2000.217.1343

19. Fan C, Zhang D. Wald-type rank test: a GEE approach. *Comput Stat Data Anal*. (2014) 74:1–16. doi: 10.1016/j.csda.2013.12.004

20. Bowker RM, Linder K, Van Wulfen KK, Sonea IM. Anatomy of the distal interphalangeal joint of the mature horse: relationships with navicular suspensory ligaments, sensory nerves and neurovascular bundle. *Equine Vet J*. (1997) 29:126–35. doi: 10.1111/j.2042-3306.1997.tb01654.x

21. Hontoir F, Paques F, Simon V, Balau B, Nicaise C, Clegg P, et al. Is the T-ligament a ligament? A histological study in equine cadaver forelimbs. *Res Vet Sci*. (2020) 132:10–6. doi: 10.1016/j.rvsc.2020.05.018

22. Butcher MT, Bertram JEA, Benzuidenhout AJ. Collateral ligaments of the distal sesmoid bone in the digit of Equus: re-evaluating midstance function. *J Morphol*. (2006) 267:1177–85. doi: 10.1002/jmor.10464

23. Budras K-D, Sack WO, Röck S, Horowitz A, Berg R. Chapter 3: pelvic limb In: KD Budras, editor. *Anatomy of the horse*. *6th* ed. Hannover, Germany: Schlütersche (2011)

24. Beeman GM. The clinical diagnosis of lameness. *Comp Cont Educ Pract Vet*. (1988) 10:172–9.

25. Schumacher J, Steiger R, Schumacher J, de Graves F, Schramme M, Smith R, et al. Effects on analgesia of the distal interphalangeal joint or palmar digital nerves on lameness caused by solar pain in horses. *Vet Surg*. (2000) 29:54–8. doi: 10.1111/j.1532-950X.2000.00054.x

26. Hoerdeman M, Smith RL, Hosgood G. Duration of action of mepivacaine and lidocaine in equine palmar digital perineural blocks in an experimental lameness model. *Vet Surg*. (2017) 46:986–93. doi: 10.1111/vsu.12689

27. Adler DMT, Dambord P, Verwilghen DR. The antimicrobial activity of bupivacaine, lidocaine and mepivacaine against equine pathogens: an investigation of 40 bacterial isolates. *The Vet J*. (2017) 223:27–31. doi: 10.1016/j.tvjl.2017.05.001

frontiers | Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 26 June 2024
DOI 10.3389/fvets.2024.1415634

OPEN ACCESS

EDITED BY
Christian Peham,
University of Veterinary Medicine Vienna, Austria

REVIEWED BY
Rebeka R. Zsoldos,
Swedish University of Agricultural Sciences, Sweden
Isabel Jimenez,
Johns Hopkins University, United States

*CORRESPONDENCE
Arielle Pechette Markley
ariellemarkley@gmail.com

RECEIVED 10 April 2024
ACCEPTED 13 June 2024
PUBLISHED 26 June 2024

CITATION
Pechette Markley A, Kieves NR, Rivas LB and Shoben AB (2024) Evaluation of surface type and time of day on agility course performance.
Front. Vet. Sci. 11:1415634.
doi: 10.3389/fvets.2024.1415634

Evaluation of surface type and time of day on agility course performance

Arielle Pechette Markley[1,2]*, Nina R. Kieves[1], Linda Blake Rivas[3] and Abigail B. Shoben[4]

[1]Department of Veterinary Clinical Sciences, College of Veterinary Medicine, The Ohio State University, Columbus, OH, United States, [2]Red Sage Integrative Veterinary Partners, Fort Collins, CO, United States, [3]Sidney Kimmel Medical College, Thomas Jefferson University, Philadelphia, PA, United States, [4]Division of Biostatistics, College of Public Health, The Ohio State University, Columbus, OH, United States

Introduction: Canine agility competitions are performed on a variety of surfaces. In the equine and human literature, surface type has been associated with speed, performance, and injury risk. The aim of this study was to evaluate the effect of general surface type and time of day on calculated speed (yards per second over a measured course distance) and course performance during the UKI Agility International (UKI) U.S. Open. We hypothesized that surface type would affect calculated speed, with sand being the slowest.

Materials and methods: Data on course performance from the 2021 and 2022 events were obtained directly from UKI. The officiating judge measured course length, automatic timers recorded dogs' course times, and speeds were calculated from these values. Three surfaces (dirt, grass, and sand) were compared across three categories of courses (jumpers, standard, and speedstakes). Differences in calculated speeds and qualifying rates were estimated using generalized estimating equations (GEE) to account for multiple runs by the same handler.

Results: Among jumpers courses, those run on sand in 2021 were markedly slower than those run on dirt. Grass and dirt were more similar in terms of average calculated speed, though some courses run on grass were significantly faster than courses run on dirt and vice versa. Time of day effects observed were inconsistent, with more variability observed for dirt and sand than for grass.

Discussion: There was a notable variation in calculate speed based on surface with sand being slowest, likely due to the increased energy cost required to run on sand due to its high compliance. Calculated speeds on grass and dirt appeared generally similar, but there was substantial variability of calculated speed among various courses, making comparison of surface effects challenging. Variables within the surface itself (such as compaction level and moisture content) likely play a role in the effects of surface on speed and performance. This study provides insight into the complexity of surface effects on performance in agility dogs and highlights the need for canine-specific surface studies on the effect of surface variables and how these relate to risk of development of musculoskeletal injuries.

KEYWORDS

agility, surface, speed, sports performance, injury, canine sports medicine, biomechanics, canine agility

1 Introduction

Canine agility is a popular performance sport where dogs navigate a pre-set course of obstacles with the winner completing the course in the fastest time with the fewest number of errors. Courses include jump obstacles, tunnels, and contact obstacles such as the A-frame, seesaw, and dog walk. The variety of obstacles and course layouts present ever-changing physical demands on the dog. Combined with high speed and technicality of some courses, there is the potential of both repetitive stress injuries and acute trauma. With the high injury rate of up to 41.7% (1), there is increasing interest in determining risk factors for injury in order to better inform prevention and treatment strategies.

Canine agility performance is multidimensional, as both speed and precision are critical to success. A perfect agility performance, also commonly called a "clean run" or "qualifying run," is defined as a dog who traverses all obstacles in the correct order within standard course time and without accruing any errors, or "faults." There are a variety of common faults: knocking down jump bars; jumping off of or leaving contact obstacles prematurely; and refusing obstacles by spinning in front of, hesitating before, or turning away from obstacles rather than taking them when directed (2). If a dog takes an obstacle out of order or accumulates too many faults they are said to be "eliminated." Automatic timers are used at the first and last obstacle to record the total time in seconds that it takes for dogs to complete the course. This also allows calculation of average course speed (yards per second/YPS) based on judges' course distance measurements. Rules about what constitutes faults and eliminations, and the number of faults a given error incurs are specific to the agility organization sanctioning the event. Rules about faults may also be specific to the event itself (i.e., a local competition versus a national competition) (2).

Agility dogs often compete on a variety of surfaces, including dirt, artificial turf, sand, grass, and rubber matting. The specific surface composition determines the surface's mechanical behaviors, such as cohesion, shear, friction, and vertical displacement while undergoing load or shear forces (3–10). Extrinsic factors such as temperature, moisture level, and how the surface is maintained also affect its mechanical behaviors (11–15). The biomechanical demands on the dog vary based on the body's interaction with those specific surface properties (3, 16–23). There have been numerous studies evaluating the biomechanical interaction between specific surfaces and human and equine athletes in a variety of contexts (24–30). No studies have evaluated the biomechanical effects of surface composition interaction in dogs. In the equine and human literature, surface has been shown to be associated with injury risk (31–36). For example, Thoroughbred racehorses have a 32% higher risk of sustaining a fracture when racing on a dirt surface compared to a synthetic surface (37). The types of injuries seen are influenced by the surface composition and specific sport interaction (36, 38). Surface has also been implicated in injury in racing Greyhounds (39). While retrospective surveys have tried to evaluate associations between surface and agility dog injury (40), there is little evidence evaluating the effect of surface on agility performance.

The aim of this study was to evaluate the effect of general surface and time of day on calculated speed and course performance during the UKI Agility International (UKI) U.S. Open, a large national multi-day event with multiple runs per day completed on a variety of surfaces. We hypothesized that surface type would affect calculated speed, with sand being the slowest surface. We also hypothesized that the time of day would affect calculated speed, with lower calculated speeds on sand early in the day due to fresh harrowing conditions, and faster calculated speeds later in the day due to more compacted surface conditions.

2 Materials and methods

Data from all runs of the 2021 and 2022 UKI U.S. Open were obtained from UKI directly. The results spreadsheet acquired from UKI consisted of one row per run and included handler name, dog name, competition jump height category, course name, time (measured by the automatic timers), faults, and an indicator of if the team had been eliminated during the run. Additional information about the event was obtained from information published on the UKI website at the time of the events.

The two main outcomes (qualifying run rate and calculated speed) were inferred from this information. An individual dog "qualified" on a specific course if it had a recorded time, had zero faults, and had not been eliminated (i.e., it had a clean run). Among dogs with clean runs, speed (YPS) was calculated from the recorded time and the reported total course length. The total course length was measured by the officiating judge following standard UKI practice of measuring the shortest distance in yards between each obstacle in sequence (2). The sum of these between obstacle distances plus the length of each obstacle dogs must traverse was recorded as the total course length.

The 2021 and 2022 events were held at the Jacksonville Equestrian Center in Jacksonville Florida. Information about the type of surface in each ring was obtained directly from the venue. A general overview of the rings and surfaces is shown in Table 1. Four dirt rings were in use both years; the surface composition in that area was local Florida soil (dirt), with no specific types or subtypes noted. Two of these rings were in a climate controlled, covered area, and two of these rings were in a covered area that was not climate controlled. Two rings of grass in an outdoor, uncovered area were used both years; this surface was predominantly Bermuda grass, with small amounts of other subtypes of local Florida grass mixed in. In 2021, two additional rings were run in an outdoor arena that consisted of sand/fiber footing.

Surface maintenance was performed daily, in the morning prior to any runs. The ring preparation involved harrowing using Kiser Dragmasters, Reveal 4-n-1, and Carolina DragNfly (designed for sand/fiber rings), and two rollers that help to compact the moisture from when the surface is watered at night. The nightly maintenance involved

TABLE 1 Description of ring surfaces and environment at the 2021 and 2022 U.S. Opens.

Surface	Surface notes	Ring numbers/ notes	Environment
Dirt	Local Florida soil	1&2	Climate controlled, covered
		3&4	Outdoor, covered
Grass	Predominantly Bermuda grass	5&6	Outdoor, uncovered
Sand	Sand/fiber footing	7&8 (only used in 2021)	Outdoor, uncovered

adding water to the surface to increase the moisture of the substrate. There was no specific amount of water used and the amount added was based on operator discretion in relation to the weather and humidity at the time. During the competition day, the surface was not refreshed at any time during the daytime, but when rings were combined and reset before evening event finals, they would perform a refresh of the surface.

Both 2021 and 2022 UKI U.S. Opens could be entered by any dog and handler team registered with UKI. Competitors could choose which of several events to enter (e.g., Biathlon, Masters series, and Speedstakes). Some events consisted of multiple courses, and some courses required a certain level of performance in an earlier course to participate (e.g., speedstakes final took only dogs who achieved a top score in the speedstakes semi-final). Courses were categorized into three classes: standard classes that include all obstacles including jumps and contact obstacles; jumpers classes that include jumps, tunnels, and weaves, but no contact obstacles; and speedstakes classes that include only regular bar jumps and tunnels (41).

During both events, competitors were randomly assigned to "rotation groups," which meant that the time of day a particular dog was running a particular course was a function of their randomly assigned group. Signalment information on the dogs competing was not available; however, information about the height of the dog was inferred from their competition jump height. Dogs were assigned to a competition jump height category based on their height at the withers; handlers could optionally elect to jump one height category lower for any reason ("select class").

We evaluated difference in qualifying run rates and average calculated speed (YPS) among classes that had some variation in surface; the jumpers classes in 2021 (5 courses, 1 on dirt, 2 on grass, and 2 on sand), the jumpers classes in 2022 (4 courses, 3 on dirt, 1 on grass), and the speedstakes semi-final course in 2022 that was run on both grass on dirt. The speedstakes semi-final course in 2022 is a unique comparison as the course was the same for both the grass and dirt surface. The other comparisons are among courses in the same class (jumpers) but varied in course design.

Models to estimate these differences used all available runs from each year and adjusted for specific course, height category and if the dog was running in the select class. All models used the method of generalized estimating equations (GEE) with robust standard errors adjusted for clustering among runs from the same handler.

To evaluate the potential impact of time of day on calculated speed and qualifying rate by general surface type, we fit models examining the impact of rotation group on calculated speed (YPS) and qualifying rate using GEE. These models were fit separately for each of the three classes (standard, jumpers, and speedstakes) by year and allowed the impact of rotation group to vary by surface type within each class.

All analyses were performed using Stata version 15.1. All *p*-values are presented unadjusted for multiple comparisons, except within year and class, we indicated pairwise comparisons that were significant after Holm correction. We considered the analysis of differences in speed by surface to be the primary analyses.

3 Results

For the 2021 event, there were 458 handlers running 706 unique dogs across the entire event. Most handlers ran one ($n = 267$, 58%) or two ($n = 149$, 33%) dogs, with 9% of handlers ($n = 42$) running three or more dogs. The 2022 event was somewhat larger with 553 unique handlers running 870 unique dogs. The percentage of handlers running one ($n = 298$, 54%), two ($n = 206$, 37%), or three or more dogs ($n = 49$, 9%) was similar to 2021.

In 2021, a total of 2,216 jumpers runs were recorded across five different courses (593 on dirt on one course, 931 across two courses on grass, and 692 across two courses on sand). In 2022, a total of 2,262 jumpers runs were recorded across four different courses (1,790 across three courses on dirt and 472 on one course on grass). Also in 2022, the same speedstakes course was run on both grass (538 runs) and dirt (275 runs). Additional runs on dirt were evaluated in both 2021 and 2022 for standard and speedstakes classes (Table 2). In both 2021 and 2022, qualifying run rates and average calculated speed (YPS) varied by the type of course and the individual course itself (Table 2), with higher calculated speeds observed for the speedstakes type courses (only jumps and tunnels) and lower calculated speeds and somewhat less variable calculated speeds for standard courses that included contact obstacles.

3.1 Surface effects on calculated speed

In 2021, the mean calculated speed for both jumpers courses run on sand was significantly lower than mean calculated speed for the jumpers course run on dirt (0.42 and 0.75 YPS slower; Table 3 and Figure 1). The two sand courses were also significantly slower than one of the courses run on grass, but they were closer in calculated speed to the other grass course, with one course run on sand faster and the other slower than the slowest grass course. There was significant variation in calculated speed between the two jumpers courses run on grass, where one course was significantly faster than dirt and the other was significantly slower (Table 3).

In 2022, there was significant variability in the calculated speeds among the three jumpers courses run on dirt and the single jumpers course run on grass (Table 3 and Figure 2). The course run on grass was significantly faster than two of the three jumpers courses run on dirt, but was significantly slower than the third jumpers course run on dirt. The same speedstakes course was run on both grass and dirt in 2022; the mean calculated speed was significantly higher on grass than dirt (0.35 YPS higher, 95% CI: 0.22 to 0.48 higher; Table 3).

3.2 Time of day effects on calculated speed

In 2021, effects of time of day on calculated speed on dirt were inconsistent by class type (Figures 3A–C and Supplementary Table S1). In jumpers classes, the lowest calculated speeds were observed midday, with higher calculated speeds observed during earlier and later rotations. In speedstakes classes, lower calculated speeds were observed later in the day, while for standard classes, higher calculated speeds were observed later in the day. There was very little variation observed by time of day for calculated speed on grass (Figure 3D and Supplementary Table S1). In contrast on sand, slower calculated speeds were observed later in the day (Figure 3E and Supplementary Table S1).

In 2022, the effects of time of day by class type on dirt were again inconsistent (Figures 4A–C and Supplementary Table S2). There was

TABLE 2 Percentage of qualifying runs and mean calculated speed (YPS) speeds for all courses run in the 2021 and 2022 U.S. Open.

Year – class	Surface	*N* runs	*N* clean (%)	Mean YPS (*sd*)
Jumpers classes – 2021				
2021 – Biathlon Jumping	Dirt	593	95 (16.0%)	5.5 (0.8)
2021 – Masters Final Jumping	Grass	405	92 (22.7%)	5.1 (0.6)
2021 – Winner Take All	Grass	526	109 (20.7%)	6.0 (0.7)
2021 – Last Chance Masters Jumping	Sand	298	58 (19.5%)	5.4 (0.6)
2021 – UKI Nationals Round 1	Sand	394	63 (16.0%)	5.0 (0.5)
Jumpers classes – 2022				
2022 – Masters Final Jumping	Grass	472	50 (10.6%)	5.7 (1.0)
2022 – Winner Take All	Dirt	695	261 (37.6%)	6.3 (0.8)
2022 – Biathlon Jumping	Dirt	692	161 (23.3%)	5.6 (0.7)
2022 – UKI Nationals Round 1	Dirt	403	49 (12.2%)	5.3 (0.7)
Standard classes – 2021				
2021 – Last Chance Masters Agility	Dirt	310	32 (10.3%)	5.3 (0.7)
2021 – Masters Final Agility	Dirt	413	87 (21.1%)	4.9 (0.6)
2021 – UKI Nationals Round 2	Dirt	339	76 (22.4%)	5.0 (0.6)
Standard classes – 2022				
2022 – Last Chance Masters Agility	Dirt	348	19 (5.5%)	5.2 (0.6)
2022 – Masters Final Agility	Dirt	499	108 (21.6%)	5.1 (0.8)
2022 – UKI Nationals Round 2	Dirt	425	61 (14.4%)	5.0 (0.8)
2022 – US Open Agility	Dirt	677	90 (13.3%)	5.2 (0.6)
Speedstakes classes – 2021				
2021 – Power and Speed (speed portion)	Dirt	414	91 (22.0%)*	5.4 (0.5)
2021 – Speedstakes Round 1	Dirt	665	235 (35.3%)	5.7 (0.7)
Speedstakes classes – 2022				
2022 – Speedstakes Round 1 (group A)	Dirt	275	74 (26.9%)	5.5 (0.7)
2022 – Speedstakes Round 1 (group B)	Grass	538	76 (14.1%)	6.3 (0.8)

For each course, the number of dogs who started the course (*N* runs) is reported, as well as the number who ran the course as described without any errors or faults (*N* clean). From these, the percentage of dogs who ran clean (%) is calculated and reported. Among the dogs who ran clean, the mean calculated speed as Yards Per Second (YPS) is reported as well as the standard deviation (*sd*) of these values. *Of all dogs that started the Power & Speed course, not all errors made during the speed portion.

low variability observed for the jumpers and standard classes run on dirt. For speedstakes, slower calculated speeds were observed later in the day, similar to 2021. On grass in 2022, average calculated speed was slowest during the earliest rotations in the jumpers class, but variability was high, and there was very little variability in the speedstakes class (Figures 4D,E and Supplementary Table S2).

3.3 Effects on qualifying rates

In 2022, qualifying rates for the one jumpers course run on grass were significantly lower than two of the three jumpers courses run on dirt, and slightly lower (although not statistically different) than the third (Table 4). Similarly, dogs were significantly less likely to qualify on the same speedstakes course in 2022 if running on grass than dirt (0.092 lower probability of qualifying on grass, Table 4). However, no significant differences were observed related to the probability of qualifying among the five jumpers courses run in 2021, and the direction of the estimated effects suggested dogs were more likely to qualify running on grass or sand compared to dirt (Table 4). No large differences in qualifying rates by time of day were observed in either 2021 or 2022 (Supplementary Tables S3, S4).

4 Discussion

4.1 Surface effects on calculated speed

As was hypothesized, there was a notable variation in calculated speed based on surface type with sand appearing to be a slower surface. Sand is generally a softer surface and requires a higher energy cost during running compared to running on harder surfaces (42). This higher energy cost is due to an increase in muscle activation resulting from increased joint range of motion and a decrease in muscle-tendon efficiency (42, 43). Due to the high compliance of sand, the surface also acts as a damper and reduces take-off velocity (43). The combination of these biomechanical interactions with sand, result in it being a slower surface compared to harder surfaces (44, 45).

It is important to note that the compositions of equine sand arenas, such as the one utilized at this event, are different from the

TABLE 3 Estimated differences in calculated speed for jumpers and speedstakes courses run on different surfaces.

	Mean difference in speed (YPS, 95% CI)	Significant pairwise differences*
2021 Jumpers courses		
[a]Dirt (Biathlon Jumping)	(Ref)	All significant (10 total)
[b]Grass1 (Masters Final Jumping)	−0.61 (−0.70, −0.51)	
[c]Grass2 (Winner Take All)	0.31 (0.21, 0.42)	
[d]Sand1 (Last Chance Masters)	−0.42 (−0.55, −0.30)	
[e]Sand2 (UKI Nationals Rd1)	−0.75 (−0.88, −0.63)	
2022 Speedstakes Round 1		
Dirt	(Ref)	One ($p < 0.001$)
Grass	0.35 (0.22, 0.48)	
2022 Jumpers courses		
[a]Grass (Masters Final Jumping)	(Ref)	All significant (6 total)
[b]Dirt1 (Biathlon Jumping)	−0.15 (−0.27, −0.04)	
[c]Dirt2 (Winner Take All)	0.45 (0.34, 0.56)	
[d]Dirt3 (UKI Nationals Rd1)	−0.38 (−0.52, −0.24)	

YPS, Yards Per Second; negative values indicate slower YPS relative to the reference category. 95% CI, 95% confidence interval, estimated from a model adjusted for height category, if the dog was running select, and accounting for clustering by handler. *Pairwise comparisons done within each year and type of course combination and comparisons that were significant after the Holm correction are identified. [a–e] are used as superscripts to identify pairwise differences.

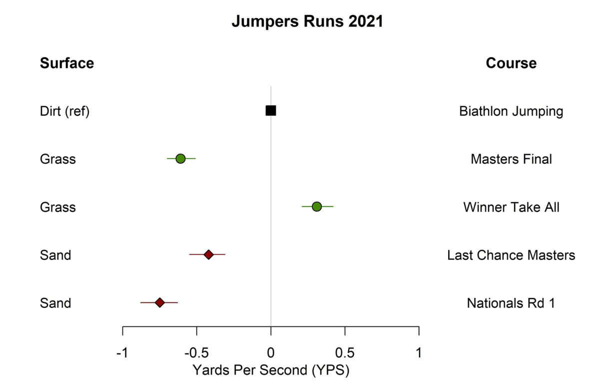

FIGURE 1
Estimated differences in calculated speed for jumpers courses run on different surfaces at the 2021 U.S. open. Estimates are adjusted for height category and if the dog was running select.

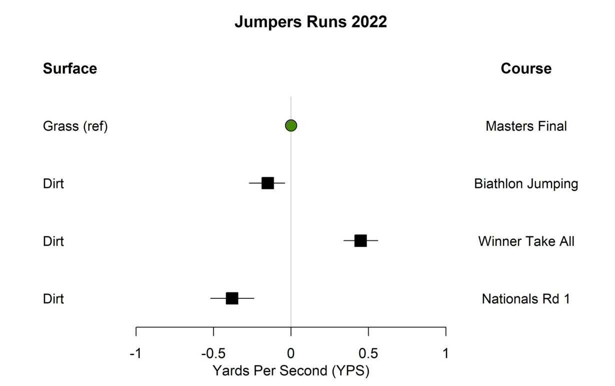

FIGURE 2
Estimated differences in calculated speed for jumpers courses run on different surfaces at the 2022 U.S. open. Estimates are adjusted for height category and if the dog was running select.

sand surfaces utilized in most human athletic events, such as beach volleyball. Most human sand studies, whether studies evaluating running on sand or studies evaluating athletic events on sand, take place on 100% sand surfaces. There are still composition and biomechanical differences in these human-utilized sand surfaces based on particle size, specific mineral content, and whether the sand is wet or dry (18). The 100% sand surfaces in human studies more closely mirror those studies in harness trotters (18, 46). The sand-like surfaces in equine arenas are considered "synthetic surfaces" because they are typically composite surfaces of sand/fiber or sand/rubber. The other components are added to sand to decrease stiffness, improve shear strength and decrease compaction of the sand (36, 47). The variation in type and size of the fibers and the type and size of the rubber affect equine biomechanics in different ways (36). It would be expected that these surface component variations would also affect canine biomechanics, though no studies have been performed to evaluate these effects.

Calculated average speeds in YPS on grass and dirt appeared generally similar, with some courses on dirt having higher calculated speeds than courses run on grass, but some courses on grass having higher calculated speeds than dirt. There was also a substantial amount of variability in calculated speed among the various jumpers courses, making comparison of surface effects challenging. The 2022 speedstakes course that was run on both dirt and grass provides a head-to-head comparison of calculated speed, with higher calculated speeds observed for grass. However, the substantially lower qualifying rate on grass raises the potential that less competitive (slower) dogs were less likely to qualify on grass, making it appear that grass was faster than dirt.

Dirt and grass have different mechanical properties that would be expected to have effects on speed (48). It has also been shown that

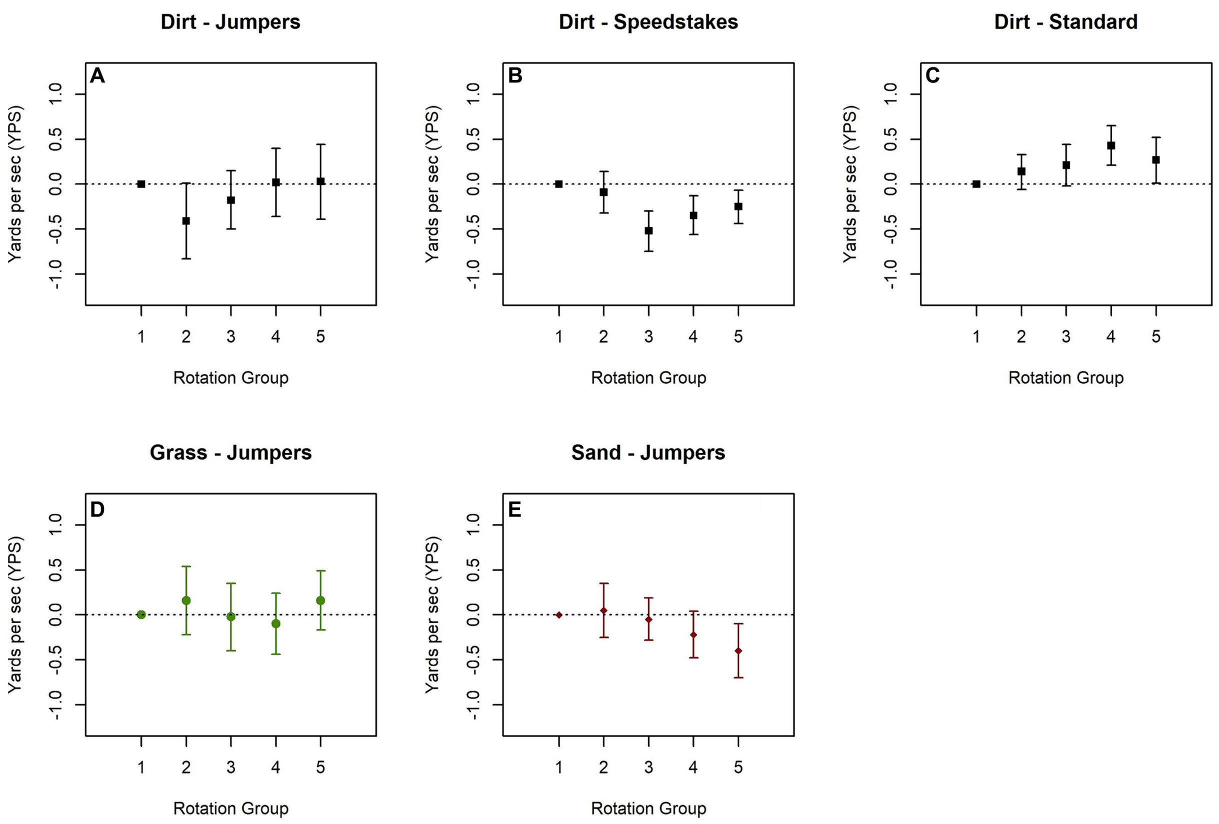

FIGURE 3
Estimated difference in calculated speed difference by order among classes run on dirt **(A–C)**, grass **(D)**, and sand **(E)** from the 2021 U.S. Open. Models are adjusted for height class and if dog is select. Plots show the trend by rotation group with the earliest group (1) used as the reference.

the incidence of fatal racing injuries in Thoroughbred racehorses is higher on dirt tracks than grass tracks (49), indicating a significant difference in biomechanical effects. However, in many human sports, grass (natural turf) fields have fallen out of favor in place of artificial turf due to the higher risk of injuries and concussions associated with playing on grass compared to artificial turf (32, 50). There are many other variables that affect the comparison between grass and dirt courses in this study, as well as across sports and species. There are significant effects of moisture content, temperature, and maintenance on grass and dirt surfaces. In Thoroughbred racing, it has been shown that speeds are higher with dry track conditions due to increased surface firmness, so the fluctuation in moisture content of the dirt and grass surfaces throughout the day could be confounding factors for course speed (48). Temperature has also been shown to affect surface mechanics as well as speed during racing (14, 51). Surfaces with higher temperatures have been shown to have reduced vertical displacement of the surface and reduced vertical impulse, thereby potentially increasing speed (51). In this study, the dirt surfaces were all covered (and half were in a climate-controlled building), and the grass surfaces were exposed, which leads to the potential for temperature to be a confounding variable for the comparison of dirt versus grass in this study.

4.2 Time of day effects on calculated speed

The type and schedule of arena surface maintenance varies by agility event. Surface maintenance for dirt and synthetic surfaces can include adjusting the moisture content and adjusting the depth of the top layer of the material, also known as the uncompacted layer. The moisture content is adjusted through watering the material. The depth of the uncompacted layer can be increased by harrowing, i.e., using specialized equipment to rake/groom the surface thereby loosening the material, or the depth can be decreased by compacting the surface using rollers. These UKI events primarily performed harrowing in the morning before the event started and watering with compacting at night. The surface was not maintained during the day and therefore, it can be assumed that as dogs ran on the surface, the surface properties changed throughout the day in the absence of maintenance. For the synthetic and dirt surfaces, the cushion depth is going to be greatest in the morning after harrowing. This could potentially result in slower speeds and increased energy expenditure, thereby resulting in lower qualifying rates if dogs were more likely to fault due to the cushion depth (51). Since the surfaces were not harrowed throughout the day, it would be expected that as the surface compacted that the vertical displacement would decrease, resulting in faster speeds, and also resulting in higher impact forces and potentially increased injury risk (51).

However, when evaluating the time-of-day effects from this event, the results were not consistent with these expectations. There was a noticeable order effect on dirt for speedstakes, where later runs were actually slower (particularly midday) in both 2021 and 2022, which is opposite of the expected effect of surface compaction. This same pattern was not consistently observed for dirt on standard courses. There was a small trend in a similar direction for standard runs in 2022, but a larger trend in opposite direction for standard runs in 2021. Sand had lower calculated speeds late in the day (jumpers from 2021) and

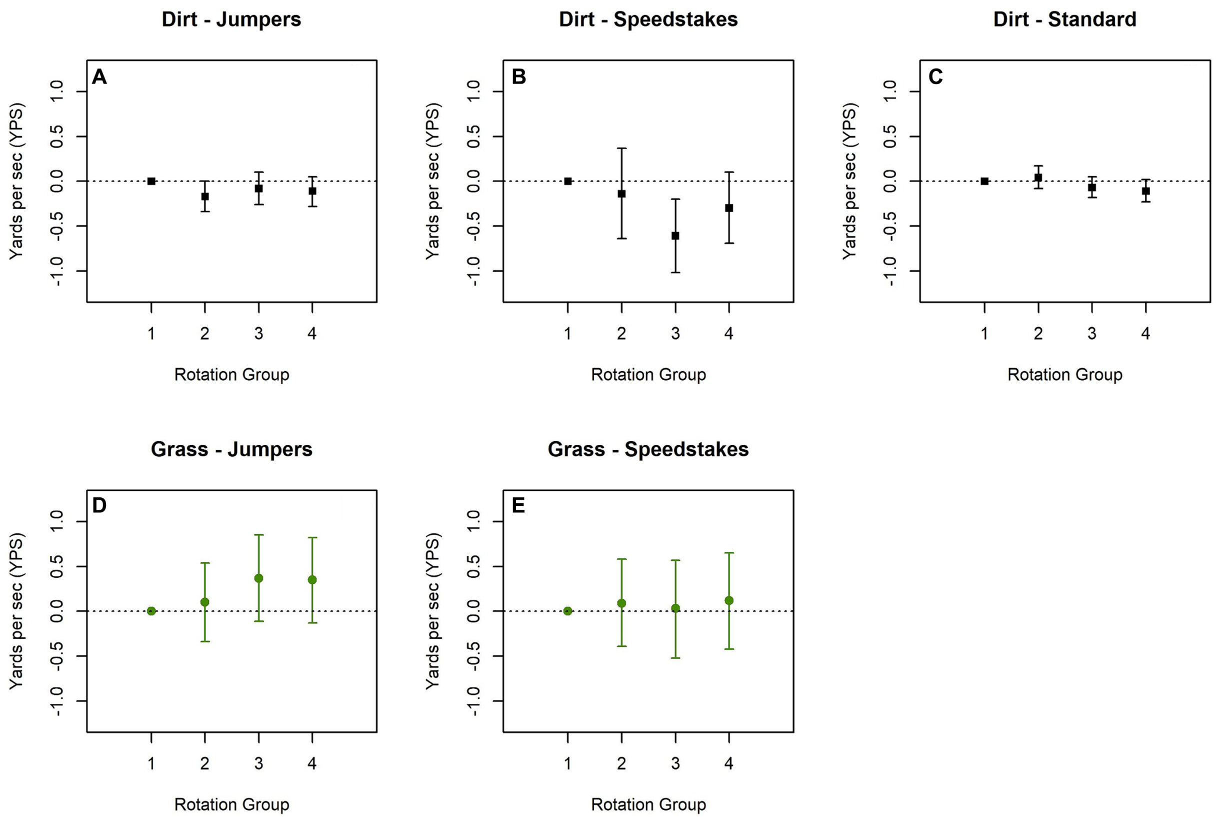

FIGURE 4
Estimated difference in calculated speed difference by order among classes run on dirt **(A–C)** and grass **(D, E)** from the 2022 U.S. Open. Models are adjusted for height class and if dog is select. Plots show the trend by rotation group with the earliest group (rotations 1 and 2) used as the reference.

TABLE 4 **Estimated differences in probability of qualifying for jumpers and speedstakes courses run on different surfaces.**

	Mean difference in probability of qualifying (95% CI)	Significant pairwise differences*
2021 Jumpers courses		
[a]Dirt (Biathlon Jumping)		None (10 total)
[b]Grass1 (Masters Final Jumping)	0.045 (−0.003, 0.924)	
[c]Grass2 (Winner Take All)	0.056 (0.014, 0.097)	
[d]Sand1 (Last Chance Masters)	0.057 (0.003, 0.111)	
[e]Sand2 (UKI Nationals Rd1)	0.014 (−0.029, 0.056)	
2022 Speedstakes Round 1		
Dirt	(Ref)	One ($p < 0.001$)
Grass	−0.092 (−0.144, −0.040)	
2022 Jumpers courses		
[a]Grass (Masters Final Jumping)	(Ref)	All significant except a vs. d
[b]Dirt1 (Biathlon Jumping)	0.134 (0.096, 0.172)	
[c]Dirt2 (Winner Take All)	0.282 (0.239, 0.325)	
[d]Dirt3 (UKI Nationals Rd1)	0.032 (−0.004, 0.069)	

Positive differences in probability of qualifying indicate larger probability of qualifying relative to the reference category. 95% CI, 95% confidence interval, estimated from a model adjusted for height category, if the dog was running select, and accounting for clustering by handler. *Pairwise comparisons done within each year and type of course combination and comparisons that were significant after the Holm correction are identified. [a–e] are used as superscripts to identify pairwise differences.

dogs were less likely to qualify on sand early in the day. Therefore, it is likely that other surface variables, such as moisture content and temperature, could be affecting these results. The other consideration is the effect of ruts created by the dogs running the same course throughout the day. While there are no studies that have evaluated the effects of ruts on speed, performance, or injury in agility dogs, it is possible that the more compliant the surface, the more likely there are to be ruts created over time. These ruts could cause dogs to slow down or even fault depending on how the line of the dog corresponds to the ruts. It is also possible that smaller dogs may be more affected by these ruts than larger dogs. The impact of ruts on equine performance is likely less due to the regular harrowing and larger size of the horse compared to the dog. Regular surface maintenance and harrowing of equine arenas are recommended during equine performance training and events in order to prevent surface compaction and reduce risk of injury but it is unknown if a similar recommendation should be made for agility dogs (51).

Variation in grass surface is also likely to influence speed, performance and potentially injury rates. While grass surfaces are less prone to the effects of compaction as synthetic or dirt surfaces, and therefore require less maintenance throughout the day, they may be more prone to environmental (temperature and weather) and moisture effects. In areas where humidity is high, like Florida, grass will often be wet in the morning, potentially resulting in more slipping during jumping and tight turns that could affect both course speeds and qualifying rates. However, there was very little difference in calculated speed or qualifying rate by time of day for all courses run on grass. This may indicate that grass is a more consistent surface, regardless of environmental effects, or it is possible that the observed days had limited variation in environmental effects.

4.3 Effects on qualifying rates

In 2021, dogs were somewhat more likely to have qualifying jumpers runs on grass and sand than on dirt. In 2022, dogs were far less likely to qualify on grass than on dirt. It is unknown whether the differences in qualifying rates were due directly to surface effects on speed and biomechanics, or whether they were due to differences in course design, the specific dogs running those courses, surface mechanics factors, or environmental factors. It is possible that the specific combination of surface and type of course, whether it is a more technical course with tighter turns and more complex handling versus a wide-open running course, could also influence qualifying rates and speeds. For example, it is possible that even though sand is a generally slower surface, there may not be as much of an effect on performance for wide open running courses as the more technical courses where the sand would have a larger effect on the ability to accelerate after the greater and more frequent decelerations required to navigate a technical course.

4.4 Limitations

One factor that makes evaluating agility performance complex and challenging, particularly with regards to the effects of surface, is the handler component. Since agility is a handler-directed sport, the biomechanical effects of the surface not only affect the dog, but also the handler. The effects of surface on the handler may make it more or less difficult for the handlers to navigate the course, thereby affecting the timing of directions and cues and causing variation in the speed and accuracy of their dog's performance. This effect is likely more noticeable in technical courses (e.g., biathlon) and less noticeable in wide open courses where dogs are likely to make accurate assumptions about where to go without handler cues.

Limitations of this study include the small number of qualifying runs, the variability in course design associated with a real event, and lack of information about specific faults. The small number of qualifying runs and no information about partial split times limited our ability to make full conclusions, despite a very large event, as dogs only received a calculated speed if they had no faults and were not eliminated. Also, while YPS is a reflection of dog speed as it is calculated based on the course completion time and distance between obstacles, it is only an estimate of average speed. Since UKI measures the shortest distance between obstacles to determine course yardage, the measured distance between obstacles may not accurately reflect the dog's actual running line between obstacles. The dog's traveled path is likely longer than the measured distance, and will vary based on size of the dog, speed, training, and handling, among other factors. YPS also only represents the average speed, which does not provide granular information about speed throughout the course, or acceleration and deceleration, all of which could provide valuable information about agility course performance.

With the exception of the 2022 speedstakes course that was run on both grass and dirt, specific individual courses were only run on one substrate. Thus, it is unknown how much the course design contributed to the differences in course performance versus the surface itself. It is also possible that the course design masked some of the surface effects on course performance, and without course design variations the surface effects would have been larger. The relatively smaller variability in calculated speed among standard courses that were all run on dirt both years, may reflect less variability in course design for standard courses or may reflect more similar calculated speeds on a consistent substrate (dirt) compared to jumpers courses. Additionally, as a real event, handlers could choose which events to enter and may have strategically entered some events and not others for a variety of unknown reasons. Likewise, as these events took place shortly after the COVID-19 pandemic, the group of handlers and dogs competing (particularly in 2021) may not fully reflect the population of agility dogs and handlers who would attend such events in future years.

Limitations also included lack of detail about variables within the surface itself, such as specific surface composition, wet versus dry grass, moisture content of the dirt and synthetic sand surfaces, compaction level, environmental humidity levels, and surface maintenance. While the general surface type was provided by the venue, this information was not based on laboratory testing of the surface composition, so exact details of the surface were unknown. We were also not able to assess the environmental factors present throughout the day, such as heat and humidity, both of which not only affect the surface mechanical properties, but also canine exercise physiology. We also could not evaluate associations between faulting of specific obstacles based on surface, time of day or with specific environmental effects. We were unable to assess the effect of surface on the handlers and how that impacted dog speed and performance. Controlled studies will be needed to evaluate these surface and performance variables individually. Despite the numerous limitations, this study provides valuable real-world data from a large number of dogs running the same courses in a random order throughout the day.

4.5 Conclusion

Since surface has been demonstrated to contribute to musculoskeletal injury, in both human and equine athletes, it is critical to determine what effects surface has on agility dog biomechanics, performance, and injury. This study provides insight into the complexity of surface effects on performance in agility dogs. It highlights the need for canine-specific surface studies and, in particular, studies on the effect of surface variables on canine agility kinetics and kinematics of performance and how these relate to risk of development of musculoskeletal injuries. Biomechanical and injury studies may help to determine a preferred surface type for agility, both for dog safety and competitiveness. A greater understanding of the complex interactions between surface, biomechanics, and injury is needed to improve the health and longevity of canine agility athletes.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The requirement of ethical approval was waived by The Ohio State University Office of Responsible Research Practices (ORRP) for the studies involving animals because it was a retrospective evaluation of non-sensitive animal data. The studies were conducted in accordance with the local legislation and institutional requirements.

Author contributions

AP: Conceptualization, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. NK: Investigation, Writing – original draft, Writing – review & editing. LR: Investigation, Writing – original draft, Writing – review & editing. AS: Conceptualization, Data curation, Formal Analysis, Methodology, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

Thank you to Greg Derrett and UKI Agility International (UKI) for providing the data from the UKI Open events.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2024.1415634/full#supplementary-material

References

1. Pechette Markley A, Shoben AB, Kieves NR. Internet-based survey of the frequency and types of orthopedic conditions and injuries experienced by dogs competing in agility. *J Am Vet Med Assoc*. (2021) 259:1001–8. doi: 10.2460/javma.259.9.1001

2. UK Agility International – Rules and Regulations Ninth Edition (n.d.). Available at: https://ukagilityinternational.com/onewebmedia/UKI%209th%20Edition%20Rule%20Book%20v3.pdf (Accessed June 2, 2024).

3. Dixon SJ, Batt ME, Collop AC. Artificial playing surfaces research: a review of medical, engineering and biomechanical aspects. *Int J Sports Med*. (1999) 20:209–18. doi: 10.1055/s-2007-971119

4. Nigg BM, Yeadon MR. Biomechanical aspects of playing surfaces. *J Sports Sci*. (1987) 5:117–45. doi: 10.1080/02640418708729771

5. Lewis K, Northrop AJ, Crook GM, Mather J, Martin JH, Holt D, et al. Comparison of equipment used to measure shear properties in equine arena surfaces. *Biosyst Eng*. (2015) 137:43–54. doi: 10.1016/j.biosystemseng.2015.07.006

6. Holt D, Northrop A, Owen A, Martin J, Hobbs SJ. Use of surface testing devices to identify potential risk factors for synthetic equestrian surfaces. *Procedia Eng*. (2014) 72:949–54. doi: 10.1016/j.proeng.2014.06.160

7. Kruse L, Traulsen I, Krieter J. The use of a technical device for testing the sport-functional properties of riding surfaces. *J Equine Vet*. (2013) 33:539–46. doi: 10.1016/j.jevs.2012.08.008

8. Northrop AJ, Hobbs SJ, Holt D, Clayton-Smith E, Martin JH. Spatial variation of the physical and biomechanical properties within an equestrian arena surface. *Procedia Eng*. (2016) 147:866–71. doi: 10.1016/j.proeng.2016.06.288

9. Peterson ML, Wayne McIlwraith C, Reiser RF. Development of a system for the in-situ characterisation of thoroughbred horse racing track surfaces. *Biosyst Eng*. (2008) 101:260–9. doi: 10.1016/j.biosystemseng.2008.07.007

10. Wannop JW, Foreman T, Madden R, Stefanyshyn D. Influence of the composition of artificial turf on rotational traction and athlete biomechanics. *J Sports Sci*. (2019) 37:1849–56. doi: 10.1080/02640414.2019.1598923

11. Herholz C, Siegwart J, Nussbaum M, Studer MH-P, Burgos S. Large temporal variations of functional properties of outdoor equestrian arena surfaces and a new concept of evaluating reactivity with light weight deflectometer settlement curves. *J Equine Vet*. (2023) 129:104909. doi: 10.1016/j.jevs.2023.104909

12. Charalambous L, von Lieres und Wilkau HC, Potthast W, Irwin G. The effects of artificial surface temperature on mechanical properties and player kinematics during landing and acceleration. *J Sport Health Sci*. (2016) 5:355–60. doi: 10.1016/j.jshs.2015.01.013

13. Peterson ML, McIlwraith CW. Effect of track maintenance on mechanical properties of a dirt racetrack: a preliminary study. *Equine Vet J*. (2008) 40:602–5. doi: 10.2746/042516408x330347

14. Peterson ML, Reiser RF, Kuo PH, Radford DW, McIlwraith CW. Effect of temperature on race times on a synthetic surface. *Equine Vet J*. (2010) 42:351–7. doi: 10.1111/j.2042-3306.2010.00072.x

15. Ratzlaff MH, Hyde ML, Hutton DV, Rathgeber RA, Balch OK. Interrelationships between moisture content of the track, dynamic properties of the track and the locomotor forces exerted by galloping horses. *J Equine Vet*. (1997) 17:35–42. doi: 10.1016/S0737-0806(97)80456-X

16. Calderón-Pellegrino G, Gallardo L, Paredes-Hernández V, García-Unanue J, Giménez JV, Colino E, et al. Influence of artificial turf temperature on physical performance and muscle contractile properties in football players after a repeated-sprint ability test. *Sci Rep*. (2020) 10:12747. doi: 10.1038/s41598-020-69720-6

17. Gustås P, Johnston C, Drevemo S. Ground reaction force and hoof deceleration patterns on two different surfaces at the trot. *ECP*. (2006) 3:209–16. doi: 10.1017/S147806150667607X

18. Crevier-Denoix N, Robin D, Pourcelot P, Falala S, Holden L, Estoup P, et al. Ground reaction force and kinematic analysis of limb loading on two different beach sand tracks in harness trotters. *Equine Vet J Suppl*. (2010) 42:544–51. doi: 10.1111/j.2042-3306.2010.00202.x

19. Crevier-Denoix N, Pourcelot P, Ravary B, Robin D, Falala S, Uzel S, et al. Influence of track surface on the equine superficial digital flexor tendon loading in two horses at high speed trot. *Equine Vet J*. (2009) 41:257–61. doi: 10.2746/042516409x394445

20. Crevier-Denoix N, Falala S, Holden-Douilly L, Camus M, Martino J, Ravary-Plumioen B, et al. Comparative kinematic analysis of the leading and trailing forelimbs of horses cantering on a turf and a synthetic surface. *Equine Vet J Suppl*. (2013) 45:54–61. doi: 10.1111/evj.12160

21. Giatsis G, Panoutsakopoulos V, Kollias IA. Drop jumping on sand is characterized by lower power, higher rate of force development and larger knee joint range of motion. *JFMK*. (2022) 7:7. doi: 10.3390/jfmk7010017

22. Giatsis G, Panoutsakopoulos V, Frese C, Kollias IA. Vertical jump kinetic parameters on sand and rigid surfaces in young female volleyball players with a combined background in indoor and beach volleyball. *JFMK*. (2023) 8:8. doi: 10.3390/jfmk8030115

23. Gaudino P, Gaudino C, Alberti G, Minetti AE. Biomechanics and predicted energetics of sprinting on sand: hints for soccer training. *J Sci Med Sport*. (2013) 16:271–5. doi: 10.1016/j.jsams.2012.07.003

24. Northrop AJ, Dagg L-A, Martin JH, Brigden CV, Owen AG, Blundell EL, et al. The effect of two preparation procedures on an equine arena surface in relation to motion of the hoof and metacarpophalangeal joint. *Vet J*. (2013) 198:e137–42. doi: 10.1016/j.tvjl.2013.09.048

25. Oosterlinck M, Royaux E, Back W, Pille F. A preliminary study on pressure-plate evaluation of forelimb toe-heel and mediolateral hoof balance on a hard vs. a soft surface in sound ponies at the walk and trot. *Equine Vet J*. (2014) 46:751–5. doi: 10.1111/evj.12210

26. Openshaw G, Northrop AJ, Brigden C, Martin JH. Preliminary investigation of maximal fetlock extension during jump landing phase on two arena surfaces; two dimensional motion analysis. *BSAP Occas Publ*. (2006) 35:243–6. doi: 10.1017/S0263967X00042816

27. Orlande O, Hobbs SJ, Martin JH, Owen AG, Northrop AJ. Measuring hoof slip of the leading limb on jump landing over two different equine arena surfaces. *Cep*. (2012) 8:33–9. doi: 10.3920/CEP11011

28. Pauchard M, Chateau H, Camus M, Ravary-Plumioen B, Falala S, Martino J, et al. Effects of speed on the vertical amplitude of the stride in trotters--comparison between fore- and hindlimbs, and influence of the track surface. *Comput Methods Biomech Biomed Engin*. (2014) 17:144–5. doi: 10.1080/10255842.2014.931555

29. Zanetti EM, Bignardi C, Franceschini G, Audenino AL. Amateur football pitches: mechanical properties of the natural ground and of different artificial turf infills and their biomechanical implications. *J Sports Sci*. (2013) 31:767–78. doi: 10.1080/02640414.2012.750005

30. Sultan O, Nuhmani S, Muaidi QI. Comparison of plantar loading patterns on natural grass and artificial turf during various athletic activities. *J Sports Med Phys Fitness*. (2021) 61:680–6. doi: 10.23736/S0022-4707.21.11342-8

31. Mack CD, Hershman EB, Anderson RB, Coughlin MJ, McNitt AS, Sendor RR, et al. Higher rates of lower extremity injury on synthetic turf compared with natural turf among national football league athletes: epidemiologic confirmation of a biomechanical hypothesis. *Am J Sports Med*. (2019) 47:189–96. doi: 10.1177/0363546518808499

32. Kuitunen I, Immonen V, Pakarinen O, Mattila VM, Ponkilainen VT. Incidence of football injuries sustained on artificial turf compared to grass and other playing surfaces: a systematic review and meta-analysis. *EClinicalMedicine*. (2023) 59:101956. doi: 10.1016/j.eclinm.2023.101956

33. Gould HP, Lostetter SJ, Samuelson ER, Guyton GP. Lower extremity injury rates on artificial turf versus natural grass playing surfaces: a systematic review. *Am J Sports Med*. (2023) 51:1615–21. doi: 10.1177/03635465211069562

34. Murray RC, Walters JM, Snart H, Dyson SJ, Parkin TDH. Identification of risk factors for lameness in dressage horses. *Vet J*. (2010) 184:27–36. doi: 10.1016/j.tvjl.2009.03.020

35. Moyer W, Spencer PA, Kallish M. Relative incidence of dorsal metacarpal disease in young thoroughbred racehorses training on two different surfaces. *Equine Vet J*. (1991) 23:166–8. doi: 10.1111/j.2042-3306.1991.tb02748.x

36. Tranquille CA, Walker VA, Roepstorff L, Hernlund E, Murray RC. Can we use information on the mechanical properties of waxed sand/fibre, sand/fibre and sand/rubber arena surfaces to help understand injury prevention? *Equine Vet J*. (2013) 45:4–5. doi: 10.1111/evj.12145_10

37. Georgopoulos SP, Parkin TDH. Risk factors for equine fractures in thoroughbred flat racing in North America. *Prev Vet Med*. (2017) 139:99–104. doi: 10.1016/j.prevetmed.2016.12.006

38. Balazs GC, Pavey GJ, Brelin AM, Pickett A, Keblish DJ, Rue J-PH. Risk of anterior cruciate ligament injury in athletes on synthetic playing surfaces: a systematic review. *Am J Sports Med*. (2015) 43:1798–804. doi: 10.1177/0363546514545864

39. Sicard GK, Short K, Manley PA. A survey of injuries at five greyhound racing tracks. *J Small Anim Pract*. (1999) 40:428–32. doi: 10.1111/j.1748-5827.1999.tb03117.x

40. Jimenez IA, Canapp SO, Percival ML. Internet-based survey evaluating the impact of ground substrate on injury and performance in canine agility athletes. *Front Vet Sci*. (2022) 9:1025331. doi: 10.3389/fvets.2022.1025331

41. Classes | UK Agility International (n.d.). Available at: https://ukagilityinternational.com/compete/classes (Accessed March 25, 2024).

42. Pinnington HC, Lloyd DG, Besier TF, Dawson B. Kinematic and electromyography analysis of submaximal differences running on a firm surface compared with soft, dry sand. *Eur J Appl Physiol*. (2005) 94:242–53. doi: 10.1007/s00421-005-1323-6

43. Lejeune TM, Willems PA, Heglund NC. Mechanics and energetics of human locomotion on sand. *J Exp Biol*. (1998) 201:2071–80. doi: 10.1242/jeb.201.13.2071

44. Jafarnezhadgero A, Amirzadeh N, Fatollahi A, Siahkouhian M, Oliveira AS, Granacher U. Effects of Running on Sand vs. Stable ground on kinetics and muscle activities in individuals with over-pronated feet. *Front Physiol*. (2021) 12:822024. doi: 10.3389/fphys.2021.822024

45. Jafarnezhadgero A, Fatollahi A, Amirzadeh N, Siahkouhian M, Granacher U. Ground reaction forces and muscle activity while walking on sand versus stable ground in individuals with pronated feet compared with healthy controls. *PLoS One*. (2019) 14:e0223219. doi: 10.1371/journal.pone.0223219

46. Chateau H, Holden L, Robin D, Falala S, Pourcelot P, Estoup P, et al. Biomechanical analysis of hoof landing and stride parameters in harness trotter horses running on different tracks of a sand beach (from wet to dry) and on an asphalt road. *Equine Vet J Suppl*. (2010) 42:488–95. doi: 10.1111/j.2042-3306.2010.00277.x

47. Tranquille CA, Walker VA, Hernlund E, Egenvall A, Roepstorff L, Peterson ML, et al. Effect of superficial harrowing on surface properties of sand with rubber and waxed-sand with fibre riding arena surfaces: a preliminary study. *Vet J*. (2015) 203:59–64. doi: 10.1016/j.tvjl.2014.10.027

48. Maeda Y, Tomioka M, Hanada M, Oikawa M. Influence of track surface condition on racing times of thoroughbred racehorses in flat races. *J Equine Vet*. (2012) 32:689–95. doi: 10.1016/j.jevs.2012.02.012

49. Arthur RM. Comparison of racing fatality rates on dirt, synthetic, and turf at four California racetracks. *Amer Assn Equine*. (2010) 56:405–8.

50. Heinzelmann MM, Stokes M, Miller SM, Bunt SC, Hynan LS, Didehbani N, et al. Impact of playing surface on concussion symptoms in young American football players. *Clin J Sport Med*. (2023). doi: 10.1097/JSM.0000000000001204

51. Rohlf CM, Garcia TC, Fyhrie DP, le Jeune SS, Peterson ML, Stover SM. Arena surface vertical impact forces vary with surface compaction. *Vet J*. (2023) 293:105955. doi: 10.1016/j.tvjl.2023.105955

frontiers | Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 23 July 2024
DOI 10.3389/fvets.2024.1419206

Check for updates

OPEN ACCESS

EDITED BY
Denis J. Marcellin-Little,
University of California, Davis, United States

REVIEWED BY
Tao Wang,
University of Maryland, United States
Barbara Bockstahler,
University of Veterinary Medicine Vienna, Austria
Steven Budsberg,
University of Georgia, United States

*CORRESPONDENCE
Cara A. Blake
✉ cara.blake@gmail.com

RECEIVED 17 April 2024
ACCEPTED 08 July 2024
PUBLISHED 23 July 2024

CITATION
Blake CA, Looney AL and Merrill TD (2024) The impact of cavaletti height on dogs' walking speed and its implications for ground reaction forces.
Front. Vet. Sci. 11:1419206.
doi: 10.3389/fvets.2024.1419206

The impact of cavaletti height on dogs' walking speed and its implications for ground reaction forces

Cara A. Blake[1]*, Andrea L. Looney[2] and Tracie D. Merrill[3]

[1]Central Hospital for Veterinary Medicine, Guilford, CT, United States, [2]Central Hospital for Veterinary Medicine, North Haven, CT, United States, [3]Reese Chiropractic, Stillwater, OK, United States

Objective: The objective of this study was to investigate the effects of cavaletti pole height on temporospatial (TPS) and ground reaction force (GRF) variables as compared to a walking gait in healthy dogs.

Animals: A total of 25 client-owned dogs were included in this study.

Procedures: This study used client-owned dogs to explore the effects of cavaletti pole height on TPS and GRF variables. Dogs were first walked over a validated pressure-sensitive walkway (PSW) and then walked over the PSW over which six cavaletti poles were set. Cavaletti pole height was initially set at 2 inches and then increased incrementally to 4 inches, 6 inches, and 8 inches. TPS and GRF variables were obtained for all dogs walking across a PSW without cavaletti poles and at each cavaletti height. TPS variables were then compared to those obtained at a normal walking gait.

Results: Increasing cavaletti height resulted in significant decreases in walking gait velocity and the number of gait cycles per minute. Conversely, significant increases in gait cycle duration (duration of one complete cycle of gait, which includes the time from the initial contact of one paw to the subsequent contact of the same paw) and gait time (duration to walk the total distance on the PSW) were noted. Increases in stance time, normalized maximum force, and normalized vertical impulse were observed.

Conclusion and clinical relevance: Cavaletti height does influence TPS variables in healthy dogs at a walking gait. The effects were most notable with regard to velocity. Due to the lack of consistent velocity for all cavaletti heights, no conclusions can be drawn regarding the effect of cavaletti height on ground reaction forces. Further investigation is needed to elucidate whether it is the velocity, cavaletti height, or combination of both that impacts ground reaction force variables. When selecting cavaletti pole heights for a therapeutic exercise program, an increase in cavaletti height results in a slower walking gait.

KEYWORDS
cavaletti pole, rehabilitative therapy, pressure-sensitive walkway, kinetics, dog

1 Introduction

Objective gait analysis has gained significant attention in veterinary medicine due to its relevance to the understanding of locomotion and identifying gait abnormalities in companion animals. Force plates and pressure-sensitive walkways have been used to evaluate the kinetics of the canine gait in both research and clinical settings (1–17). Force-plate (FP) systems provide ground reaction force (GRF) information for one limb or footfall. Pressure-sensitive walkways (PSW) measure temporospatial (TPS) and ground reaction forces (GRF) information about all four limbs and multiple gait cycles (18). PSWs have been used to characterize the TPS and GRFs in different populations of dogs under various conditions (19–30).

Rehabilitative therapy is an evolving discipline within the field of veterinary medicine. There has been tremendous growth in this field, and a previous study reported that approximately 70% of veterinarians refer patients for rehabilitation (31). Therapeutic exercises are an important component of veterinary rehabilitation programs. Changes in weight bearing status are used to modify and progress therapeutic exercises in veterinary patients. Cavaletti poles are commonly included as part of a therapeutic exercise program to improve joint range of motion, balance, coordination, proprioception, and weight bearing. Cavaletti poles are typically set at a low height initially, and as the patient progresses, the pole height is increased. Additionally, cavaletti poles of varied heights, spacing, and layouts can be utilized to increase the difficulty of the exercise (32–40).

Walking over obstacles has been researched in human subjects. These human studies have shown that negotiating obstacles during locomotion is a multifaceted process that demands coordinated efforts from various physiological systems (41). Upon approaching an obstacle, its dimensions and surface properties are evaluated to formulate an ideal strategy for crossing (42). Limbs are raised, and joints are flexed and extended to clear the object. During these moments, equilibrium is sustained through the activation of core muscles and subtle adjustments in posture and limb alignment. Depending on the obstacle's size and characteristics, adaptations in gait patterns or step lengths may be warranted to ensure adequate clearance (43–48). In quadrupeds, such adjustments may entail varying degrees of articulation in the thoracic and pelvic limbs (49–51).

Bipedal and quadrupedal obstacle walking requires the negotiation of barriers but diverges in limb usage, stability, biomechanics, and energy expenditure. Bipedal locomotion, relying on two limbs, entails heightened instability and places greater demands on the musculoskeletal system (41, 42). In contrast, quadrupedal locomotion, leveraging four limbs, offers enhanced stability and energy efficiency (49–51).

When a bipedal animal confronts a vertical obstacle, the leading limb starts the movement, lifting and clearing the barrier, with the trailing limb providing stability and reinforcement. This synchronized interplay between the leading and trailing limbs facilitates agile obstacle negotiation while maintaining equilibrium (52). Conversely, in quadrupedal locomotion, a dynamic interplay occurs among the leading forelimb, trailing forelimb, leading hindlimb, and trailing hindlimb, each fulfilling specialized roles to ensure smooth traversal over vertical obstacles (49–51).

Studies have evaluated the kinematics, kinetics, and muscle activation during walking, trotting, and jumping over obstacles in dogs and horses (53–60). The effect of fence height, increasing hurdle heights, and differing distances between obstacles on jump kinematics has been reported in dogs (55–57). A study evaluating hindlimb kinematics in dogs with hip osteoarthritis when walked over carpus-height obstacles revealed changes in stifle and tarsal joint range of motion but no changes in hip joint kinematics (58). In studies investigating surface electromyography in dogs walking over obstacles, increased muscle activity of the vastus lateralis and gluteus medius was noted (59, 60).

Despite the growth in rehabilitative therapy for veterinary patients, there is still a lack of information regarding the specific exercises used in therapeutic exercise programs. Limited information is available on the gait kinetics of canines when walking over obstacles (59–62). A recent study investigated the effects of walking over one or two obstacles on ground reaction forces and the center of pressure (COP) within the paws of healthy dogs. The results demonstrated slower walking speeds, increased vertical impulse during the stance phase of the pelvic limbs, and changes in the COP when compared to walking without obstacles (63). To the authors' knowledge, there are no previously reported data published in the literature reporting information with regard to dogs walking over multiple sequential obstacles, such as cavaletti poles. The paucity of data leaves the veterinary rehabilitation practitioner to base parameters for cavaletti pole exercises on clinical experience and extrapolation from studies on other species (human and rat). Therefore, the goal of this study was to examine the impact of walking over multiple obstacles (cavaletti poles) set at increasing heights on TPS and GRF parameters in healthy dogs during a walking gait. We hypothesized that there would be differences in both TPS and GRF variables with increasing cavaletti pole height when compared to a walking gait.

2 Materials and methods

The study was approved by the Institutional Animal Care and Use Committee at Oklahoma State University. Client- and staff-owned dogs were recruited to participate in this study, and written owner consent was obtained prior to enrollment.

A complete physical, neurologic, and orthopedic exam was performed on all dogs by a board-certified veterinary surgeon (CAB). The breed, age, sex, weight, and body condition score (BCS, 1–9) were recorded. The height at the withers was measured using a commercial measuring stick[1] and recorded. Dogs were excluded from the study if they had evidence of orthopedic or neurologic disease or other systemic diseases that would adversely affect locomotion, were not amenable to leash walking, were not amenable to walking over cavaletti poles, were not amenable to walking over pressure-sensitive walkway, and/or had a measured wither height of <50 cm or >65 cm.

A PSW system[2] was used to obtain temporospatial gait and GRF measurements. The PSW was calibrated as per the manufacturer's instructions using a phantom of known weight. Data were transmitted

1 Tough1 Miniature Sure Measure Height Standard, JT International, Indianapolis, IN.

2 5-Tile High Resolution Strideway System, Tekscan Inc., South Boston, MA.

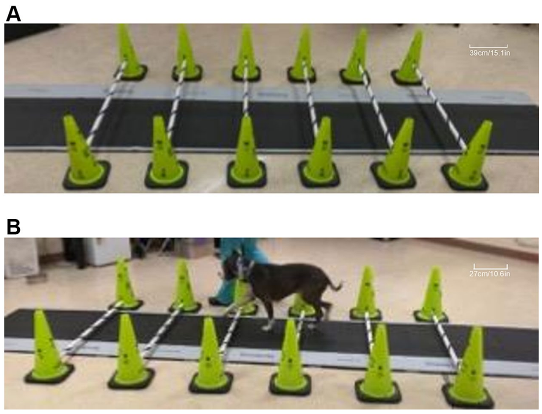

FIGURE 1
Images of cavaletti pole and pressure-sensitive walkway (PSW) setup. A representative image depicting six cavaletti poles set at the 6-inch (15.2 cm) height setup over the centrally placed PSW **(A)**. A dog with a measured withers height of 54 cm is walked on the left-hand side of the handler over calvaletti poles spaced 54 cm apart, set at the 2″ (5.1 cm) cavaletti height that were placed over the PSW **(B)**.

to a dedicated computer using Tekscan software (Strideway™ version 7.7) and subsequently exported to Microsoft Excel.

Prior to data acquisition, each dog was allowed to adapt to the room where the gait analysis was performed. Once comfortable, each dog was leash-walked around the room, over the pressure-sensitive walkway (PSW), over cavaletti poles, and over cavaletti poles that were set up over the PSW (Figure 1A). Dogs were walked on leash by the same handler (TDM), on the left-hand side of the handler. Each dog was walked at their preferred velocity over the PSW to obtain a baseline gait evaluation at a walking gait. The dogs were then walked over the PSW, at their preferred velocity, over which six cavaletti poles were set (Figure 1B). Cavaletti poles[3] were initially set at a height of 2 inches (5.1 cm) and heights were incrementally increased to 4 inches (10.2 cm), 6 inches (15.2 cm), and 8 inches (20.3 cm) over a period of 1 to 2 h. The distance between each cavaletti pole was the measured withers height of each dog. The dogs were allowed to rest for a minimum of 10 min between each increase in cavaletti pole height. The trial was considered valid if the dog had three feet on the walkway, did not pull on the leash, did not turn its head significantly off midline, and walked over the cavaletti poles one limb at a time. Each dog completed multiple trials until five valid trials were completed for each height.

Data were collected for dogs walking over the pressure-sensitive walkway (heretofore known as "walking gait") and over sequentially increasing heights of cavaletti (2 inches, 4 inches, 6 inches, and 8 inches). The temporospatial data variables collected were gait velocity (gait distance [total distance walked on the PSW]/gait time [duration to walk the total distance on the PSW]), number of gait cycles per minute (frequency at which a dog completes its gait cycles within a minute), gait cycle duration (duration of one complete cycle of gait, which includes the time from the initial contact of one paw to the subsequent contact of the same paw), and gait time (duration to walk the total distance on the PSW). The ground reaction force variables collected for each limb were maximum peak pressure, stance time, maximum force, and vertical impulse. Maximum force and vertical impulse were measured as normalized values (% body weight (kg) and % body weight (kg) x seconds, respectively).

Statistical analysis was performed, and data were analyzed using mixed models general in NCSS 2019. TPS data were analyzed using a two-factor ANOVA. The normality of the errors was evaluated using histograms and normal probability plots and accepted. Sphericity (homogeneity of the variances of the differences) was addressed by assessing various repeated covariance patterns and selecting the best (first-order autogressive) using Akaike's Information Criterion. Data were reported as mean +/− SD. The value of $p < 0.05$ was considered significant.

3 Results

In total, 32 dogs were evaluated. Of which, 25 dogs met the inclusion criteria. Seven dogs did not meet the inclusion criteria and were excluded from enrollment. Of the dogs excluded, one dog was determined to have neurologic dysfunction, three dogs had a withers height of <50 cm, and three dogs were not amenable to leash walking over the PSW. The study population included mixed breed (9), Australian Shepherd (3), Labrador Retriever (3), Doberman Pinscher (2), Golden Retriever (2), Border Collie (1), German Shepherd (1), Pitbull (1), Siberian Husky (1), Standard Poodle (1), and Visla (1). Three dogs were intact males, 14 dogs were neutered males, one dog was an intact female, and seven dogs were spayed females. The mean age of the dogs was 5.8 ± 2.9 years (range: 1.5–11 years). Mean weight and BCS were 27.5 ± 5.6 kg (range: 18–40.6 kg) and 5.28 ± 0.9 (range: 4.5–7.5), respectively. The mean withers height was 55.9 ± 4.8 cm (range: 50–65 cm).

3.1 Temporospatial variables

Walking over cavaletti poles of increasing heights resulted in significant differences in gait velocity, number of gait cycles per minute, gait cycle duration, and gait time as compared to the same variables obtained for a walking gait. The gait velocity in dogs walking over 2″, 4″, 6″, and 8″ cavaletti heights was significantly decreased compared to a walking gait ($p<0$ 0.001, Table 1; Figure 2). The number of gait cycles per minute was also significantly decreased for all cavaletti heights compared to a walking gait ($p<0.001$, Table 1; Figure 2). The converse was noted with both gait cycle duration and gait time. Increasing cavaletti height resulted in an increase in gait cycle duration for 2″ cavaletti height ($p<0.001$) in addition to 4″, 6″, and 8″ heights (p < 0.001) compared to a walking gait (Table 1; Figure 2). Gait time was also significantly increased for 2″ ($p=0.004$), 4″, 6″, and 8″ (p < 0.001) cavaletti height compared to a walking gait (Table 1; Figure 2).

3.2 Ground reaction force variables

No observed differences were noted for maximum peak pressure (Table 2). Increases in stance times were observed for all limbs at every cavaletti height (Table 3). An increase in normalized maximum force was

3 Canine Pro-Cones, Balanced Canine Products, Denver, CO.

noted in the forelimbs but not in the hindlimbs (Table 4). Additionally, increases in normalized vertical impulse were observed in both the forelimbs and hindlimbs (Table 5). Due to the lack of consistent velocity across all test groups, no comparisons or inferences were made regarding these observations for ground reaction force variables.

4 Discussion

Cavaletti poles are a common component of veterinary rehabilitation programs. These are utilized to strengthen the muscles, promote weight bearing, improve balance and proprioception, and increase the joint active range of motion. This investigational study aimed to assess the impact of walking over cavaletti poles of varying heights on temporospatial and ground reaction variables in healthy subjects, with the ultimate goal of enhancing comprehension regarding their potential utility in comparative rehabilitative therapy programs for patients with orthopedic and neuromuscular challenges.

The results of the current study demonstrated that increasing cavaletti pole height has an effect on temporospatial variables. The true effect on ground reaction force variables cannot be determined

TABLE 1 Comparison of the effects of cavaletti pole height on temporospatial measurements for dogs walked over a pressure sensitive walkway.

Variable	Walking Gait	2″ cavaletti	4″ cavaletti	6″ cavaletti	8″ cavaletti
Gait velocity (m/s)	1.11 ± 0.11[a]	0.97 ± 0.09[a]	0.89 ± 0.09[a]	0.77 ± 0.11[a]	0.66 ± 0.11[a]
No of gait cycles/min	87.40 ± 8.52[b]	79.65 ± 6.97[b]	75.26 ± 7.74[b]	69.05 ± 6.99[b]	63.09 ± 6.66[b]
Gait cycle duration (s)	0.69 ± 0.07[c]	0.76 ± 0.07[c]	0.81 ± 0.09[d]	0.88 ± 0.09[d]	0.97 ± 0.11[d]
Gait distance (m)	2.84 ± 0.09	2.84 ± 0.12	2.85 ± 0.09	2.76 ± 0.41	2.87 ± 0.09
Gait time (s)	2.54 ± 0.48[d]	2.97 ± 0.36[e]	3.24 ± 0.41[f]	3.78 ± 0.68[f]	4.55 ± 0.94[f]

Data represent mean ± SD. [a,b]Significant difference for 2”, 4”, 6”, 8” cavaletti height compared to a walking gait ($p < 0.001$). [c]Significant difference for 2” cavaletti height compared to a walking gait ($p < 0.001$). [d]Significant difference for 4”, 6”, 8” cavaletti height compared to a walking gait ($p < 0.001$). [e]Significant difference for 2” cavaletti height compared to a walking gait ($p = 0.004$). [f]Significant difference for 4”, 6”, 8” cavaletti height compared to a walking gait ($p < 0.001$).

TABLE 2 Observed maximum peak pressure (psi) for each limb.

Limb	Walking Gait	2″cavaletti	4″cavaletti	6″cavaletti	8″cavaletti
Left forelimb	45.17 ± 6.89	46.19 ± 6.98	47.78 ± 8.05	46.76 ± 7.23	47.16 ± 7.49
Right forelimb	47.44 ± 7.53[e]	49.06 ± 7.63	49.04 ± 7.55	50.08 ± 7.96	50.37 ± 7.19[e]
Left hindlimb	37.98 ± 6.79	38.66 ± 5.29	38.74 ± 5.19	38.56 ± 4.88	40.33 ± 5.78
Right hindlimb	40.61 ± 8.75	40.09 ± 5.59	40.33 ± 5.39	40.47 ± 5.13	40.99 ± 5.33

Data represent mean ± SD.

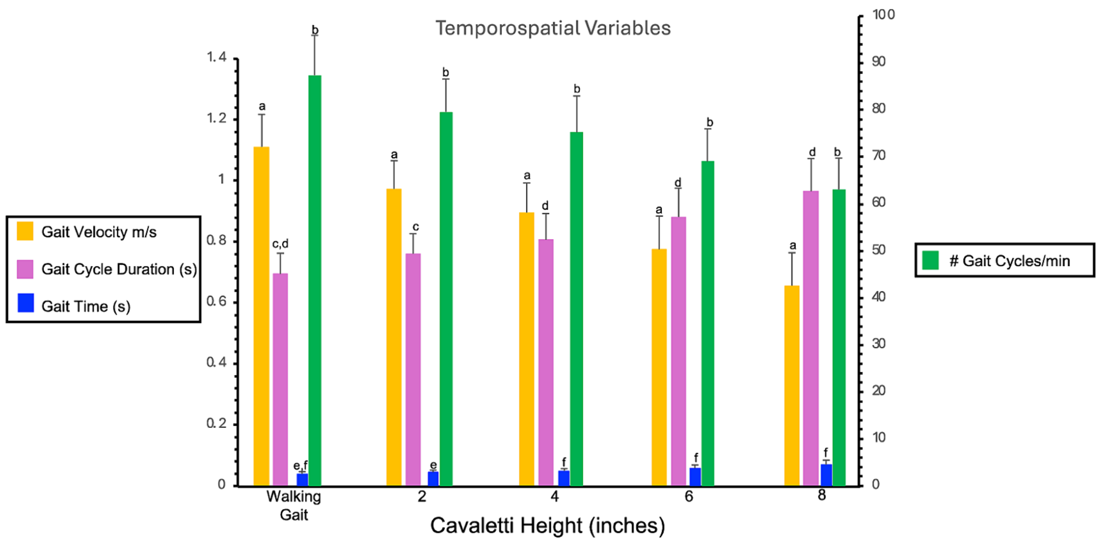

FIGURE 2
Bar graph illustrates the comparison of the effects of cavaletti pole height on gait velocity (m/s), number of gait cycles per minute, gait cycle duration (seconds), and gait time (seconds) as compared to a walking gait. Data represent mean ± SD. Gait velocity is gait distance (total distance walked on the PSW)/gait time (duration to walk the total distance on the PSW). Gait cycle duration is the duration of one complete cycle of gait, which includes the time from the initial contact of one paw to the subsequent contact of the same paw. Gait time is the duration to walk the total distance on the PSW. #gait cycles per minute is the frequency at which a dog completes its gait cycles within a minute.

TABLE 3 Observed stance time (seconds) for each limb.

Limb	Walking Gait	2″ cavaletti	4″ cavaletti	6″ cavaletti	8″ cavaletti
Left forelimb	0.41 ± 0.05	0.45 ± 0.05	0.47 ± 0.06	0.52 ± 0.06	0.56 ± 0.08[j]
Right forelimb	0.41 ± 0.05	0.45 ± 0.05	0.48 ± 0.06	0.52 ± 0.07	0.57 ± 0.08[k]
Left hindlimb	0.39 ± 0.04	0.43 ± 0.04	0.46 ± 0.06	0.50 ± 0.06	0.54 ± 0.08[l]
Right hindlimb	0.40 ± 0.04	0.44 ± 0.05	0.47 ± 0.06	0.50 ± 0.06	0.54 ± 0.08[m]

Data represent mean ± SD.

TABLE 4 Observed normalized maximum force (%BW) for each limb.

Limb	Walking Gait	2″ cavaletti	4″ cavaletti	6″ cavaletti	8″ cavaletti
Left forelimb	56.27 ± 9.59	57.37 ± 8.62	60.01± 9.72	60.63 ± 9.72	60.79 ± 9.08
Right forelimb	58.90 ± 9.72	60.53 ± 8.56	61.80 ± 9.18	64.11 ± 10.78	63.75 ± 9.85
Left hindlimb	44.22 ± 7.79	44.24 ± 8.40	44.59± 8.73	44.24 ± 8.23	45.14 ± 7.78
Right hindlimb	45.18 ± 8.44	44.80 ± 7.88	45.17 ± 7.70	45.71 ± 7.99	47.40 ± 8.56

Data represent mean ± SD.

TABLE 5 Observed normalized vertical impulse (%BW x sec) for each limb.

Limb	Walking Gait	2″ cavaletti	4″ cavaletti	6″ cavaletti	8″ cavaletti
Left forelimb	16.32 ± 3.43	18.43 ± 3.37[l]	20.35 ± 4.30	22.17 ± 3.33	23.94 ± 4.03
Right forelimb	17.26 ± 3.03	19.49 ± 3.12	20.93 ± 3.93	23.50 ± 3.87	25.67 ± 4.40
Left hindlimb	11.88 ± 1.9	12.92 ± 2.11	13.73± 2.30	14.58 ± 2.05	16.14 ± 2.81
Right hindlimb	12.59 ± 2.28	13.42 ± 2.23	14.15 ± 2.18	15.22 ± 1.98	16.87 ± 2.72

Data represent mean ± SD.

due to the lack of consistent velocity across all test groups. We therefore partially accept and partially reject our hypothesis.

Both gait velocity and the number of gait cycles per minute decreased significantly for all cavaletti pole heights when compared to a walking gait. The converse was noted for gait cycle duration and gait time, in that both variables increased. Each incremental increase in cavaletti height resulted in a corresponding decrease in gait velocity and the number of gait cycles and an increase in gait cycle duration and gait time. In human and animal studies for which obstacle walking has been investigated, both decreased velocity and cadence have been reported. Dogs walking over two 13-cm (5.1 inches) height obstacles, separated by 35 cm (13.8 inches), resulted in a significantly slower center of pressure (COP) speed as compared to a walking gait (62). A human study yielded comparable results, showing reduced obstacle-crossing speed corresponding to increased obstacle height (42). In the present study, negotiating multiple sequential obstacles resulted in changes to temporospatial variables presumably required to enable the successful navigation of the obstacles.

Gait velocity has been shown to influence ground reaction forces (63–66). Therefore, the use of a constant velocity has been recommended to minimize data variability (15). Studies have documented that as gait velocity increases, peak vertical forces increase and stance time decreases. A gait velocity ranging between 0.8 and 1.3 m/s has been reported for walking (15, 18). The dogs in this study were allowed to walk over the cavaletti poles at a comfortable pace, mirroring the approach typically adopted in clinical practice during therapeutic exercise. When using cavaletti poles in a therapeutic exercise program, dogs are typically walked slowly to encourage weight bearing on all limbs. A faster pace can often lead to the dog hopping or jumping over obstacles, avoiding the need to place the affected limb on the ground, which negates the purpose of the exercise. Therefore, to replicate clinical practice, we did not force the dogs to walk faster. Allowing each dog to navigate the obstacles at their own pace resulted in a decrease in the walking gait velocity with each incremental increase in cavaletti height. Ideally, the dogs would have walked at a set velocity for each cavaletti height. However, to maintain a constant velocity for each cavaletti height, the dogs would have needed to be led at a faster pace. Based on human and rodent studies investigating obstacle walking, a decrease in velocity was anticipated. However, the magnitude of this decrease and the specific velocity range for canine ambulation over multiple obstacles set at specific heights were unknown. The inability of the dogs to maintain a consistent velocity across all cavaletti heights highlighted the impact of increasing cavaletti height. The slower velocities observed with increasing cavaletti height suggest modifications to walking gait patterns to successfully navigate the obstacles. Gait velocity is a critical variable in canine gait analysis as it directly affects ground reaction force variables. Consequently, in this study, the increasing cavaletti height directly affected the velocity. The velocity ranges acquired for each cavaletti height may serve as a foundation for further investigation of our understanding of the dynamics of the canine gait when walking over obstacles. This information may be beneficial for therapeutic and rehabilitation purposes as controlling gait velocity may help manage the forces exerted on the dog's limbs, which is important for dogs recovering from injuries or surgeries. This information will also be valuable for future studies related to velocity and TPS and GRF variables.

Conclusions regarding the direct effect of cavaletti height on ground reaction forces cannot be drawn from the data obtained in this study. Maximum peak pressure, stance time, normalized maximum force, and normalized vertical impulse are all affected by and correlated with velocity. It is unclear whether the increases in stance time, normalized maximum force, and normalized vertical impulse observed in this study are due to the decrease in velocity, the cavaletti height, or a combination of both. To better elucidate the effects of cavaletti pole height on ground reaction forces, maintaining the same walking velocity for all cavaletti heights would be necessary.

The current study presents several limitations. Most notably, the lack of consistent velocity for all cavaletti height trials introduced variability. The absence of established velocity ranges for dogs walking over each cavaletti height prevented the assignment of a specific velocity for a particular cavaletti height. These differing velocities serve as a confounding variable when interpreting the GRF data. A comparison to a walking gait within the velocity range corresponding to a specific cavaletti height would further clarify the effects of the cavaletti height on TPS and GRF variables.

A heterogeneous population of medium to large dogs was used, resulting in a 15-cm range in withers height. A more clinically homogeneous study population might have led to reduced variability in the outcome variables. Although dogs underwent assessment for overt orthopedic disease, subclinical orthopedic diseases, such as osteoarthritis, cannot be entirely ruled out.

Radiographs could have been obtained for a more comprehensive evaluation of forelimb and hindlimb joints to exclude dogs with orthopedic disease. However, radiographic disease evidence may or may not correlate with clinical disease or soundness (67). Olsson et al. reported that clinical signs are often unrelated to radiographic severity (68). This disparity has been explored through force-plate analysis, which highlighted a poor correlation between radiographic osteoarthritis (OA) and limb function (69, 70), as well as clinician- and owner-reported pain severity, which again were not associated with radiographic severity (71). Furthermore, in comparison to human medicine, no single clinical scoring system has been accepted as the standard of care in the diagnosis of canine OA with radiography (72, 73).

Additionally, the dogs were consistently led from their right side (handler's left side) and always in the same direction over the pressure-sensitive walkway (PSW). Alternating the side from which the dogs were led and the walking direction may have provided additional insights. The sequential increase in cavaletti height was not randomized. Randomizing the height order could have mitigated potential biases. Finally, all trials were conducted within a single day, possibly impacting fatigue levels and performance consistency.

The primary aim of this study was to gain a more global understanding of both TPS and GRF in healthy dogs navigating multiple obstacles. Therefore, an in-depth examination of the dynamics of the leading and trailing forelimbs and hindlimbs was not performed. Consequently, a limitation of this study arises from the absence of detailed information regarding the leading and trailing limbs of dogs while navigating vertical obstacles. For a comprehensive understanding of the kinetics involved in walking over multiple obstacles, further research is warranted to elucidate the distinct effects on both the leading and trailing forelimbs and hindlimbs.

This investigation was conducted in a cohort of healthy dogs without overt signs of orthopedic disease or neurologic dysfunction, walking on a flat surface in a straight line. Further research is required to delve deeper into the temporospatial (TPS) and ground reaction force (GRF) variables during obstacle walking compared to walking at a slower velocity within the range corresponding to the obstacle height. Subsequent studies could also explore the influence of cavaletti height in patients with pathological conditions and varied orientations in healthy individuals as they transition back to sporting activities.

Despite the limitations of this study, the data do provide initial insight regarding walking exercises over cavaletti poles. Increasing heights resulted in slower walking velocities. This information is applicable and relevant in the clinical setting. To facilitate weight bearing and ensure the exercise is performed correctly, the height of the cavaletti poles can be increased, encouraging the dog to walk and step over each obstacle and preventing the dog from moving at a faster pace. Additional studies are warranted to further investigate the relationship between cavaletti height and ground reaction forces.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal studies were approved by Oklahoma State University Animal Care and Use Committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

CB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing. AL: Writing – review & editing, Conceptualization, Methodology. TM: Data curation, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The funding for this study was provided by the American Association of Rehabilitation Veterinarians and Purina.

Acknowledgments

The authors thank Joe G. Hauptman, DVM, MS, DACVS for assistance with statistical analysis and the clients and dogs for their participation in this study.

Conflict of interest

TM is employed by Reese Chiropractic.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Budsberg SC, Verstraete MC, Soutas-Little RW. Force plate analysis of the walking gait in healthy dogs. *Am J Vet Res*. (1987) 48:915–8.

2. Budsberg SC, Verstraete MC, Soutas-Little RW, Flo GL, Probst CW. Force plate analyses before and after stabilization of canine stifles for cruciate injury. *Am J Vet Res*. (1988) 49:1522–4.

3. Yanoff S, Hulse DA, Hogan HA, Slater M, Longnecker MT. Measurements of vertical ground reaction force in jumping dogs. *Vet Comp Orthop Traumatol*. (1992) 5:44–50. doi: 10.1055/s-0038-1633066

4. Budsberg SC, Jevens DJ, Brown J, Foutz TL, DeCamp CE, Reece L. Evaluation of limb symmetry indices, using ground reaction forces in healthy dogs. *Am J Vet Res*. (1993) 54:1569–74. doi: 10.2460/ajvr.1993.54.10.1569

5. DeCamp CE. Kinetic and kinematic gait analysis and the assessment of lameness in the dog. *Vet Clin North Am Small Anim Pract*. (1997) 27:825–40. doi: 10.1016/s0195-5616(97)50082-9

6. Lee DV, Bertram JE, Todhunter RJ. Acceleration and balance in trotting dogs. *J Exp Biol*. (1999) 202:3565–73. doi: 10.1242/jeb.202.24.3565

7. Bertram JE, Lee DV, Case HN, Todhunter RJ. Comparison of the trotting gaits of Labrador retrievers and greyhounds. *Am J Vet Res*. (2000) 61:832–8. doi: 10.2460/ajvr.2000.61.832

8. McLaughlin RM. Kinetic and kinematic gait analysis in dogs. *Vet Clin North Am Small Anim Pract*. (2001) 31:193–201. doi: 10.1016/s0195-5616(01)50045-5

9. Ballagas AJ, Montgomery RD, Henderson RA, Gillette R. Pre- and postoperative force plate analysis of dogs with experimentally transected cranial cruciate ligaments treated using tibial plateau leveling osteotomy. *Vet Surg*. (2004) 33:187–90. doi: 10.1111/j.1532-950x.2004.04027.x

10. Lee DV, Stakebake EF, Walter RM, Carrier DR. Effects of mass distribution on the mechanics of level trotting in dogs. *J Exp Biol*. (2004) 207:1715–28. doi: 10.1242/jeb.00947

11. Walter RM, Carrier DR. Ground forces applied by galloping dogs. *J Exp Biol*. (2007) 210:208–16. doi: 10.1242/jeb.02645

12. Carr BJ, Canapp SO Jr, Zink MC. Quantitative comparison of the walk and trot of border collies and Labrador retrievers, breeds with different performance requirements. *PLoS One*. (2015) 10:e0145396. doi: 10.1371/journal.pone.0145396

13. Schnabl-Feichter E, Tichy A, Gumpenberger M, Bockstahler B. Comparison of ground reaction force measurements in a population of domestic shorthair and Maine coon cats. *PLoS One*. (2018) 13:e0208085. doi: 10.1371/journal.pone.0208085

14. Amimoto H, Koreeda T, Wada N. Evaluation of recovery of limb function by use of force plate gait analysis after tibial plateau leveling osteotomy for management of dogs with unilateral cranial cruciate ligament rupture. *Am J Vet Res*. (2019) 80:461–8. doi: 10.2460/ajvr.80.5.461

15. Conzemius MG, Torres BT, Muir P, Evans R, Krotscheck U, Budsberg S. Best practices for measuring and reporting ground reaction forces in dogs. *Vet Surg*. (2022) 51:385–96. doi: 10.1111/vsu.13772

16. Humphries A, Shaheen AF, Gómez Álvarez CB. Biomechanical comparison of standing posture and during trot between German shepherd and Labrador retriever dogs. *PLoS One*. (2020) 15:e0239832. doi: 10.1371/journal.pone.0239832

17. Moreau M, Lussier B, Ballaz L, Troncy E. Kinetic measurements of gait for osteoarthritis research in dogs and cats. *Can Vet J*. (2014) 55:1057–65.

18. Kieves NR. Objective gait analysis: review and clinical applications. *Vet Clin North Am Small Anim Pract*. (2022) 52:857–67. doi: 10.1016/j.cvsm.2022.03.009

19. Lascelles BD, Roe SC, Smith E, Reynolds L, Markham J, Marcellin-Little D, et al. Evaluation of a pressure walkway system for measurement of vertical limb forces in clinically normal dogs. *Am J Vet Res*. (2006) 67:277–82. doi: 10.2460/ajvr.67.2.277

20. Gordon-Evans WJ, Evans RB, Knap KE, Hildreth JM, Pinel CB, Imhoff DJ, et al. Characterization of spatiotemporal gait characteristics in clinically normal dogs and dogs with spinal cord disease. *Am J Vet Res*. (2009) 70:1444–9. doi: 10.2460/ajvr.70.12.1444

21. Gilbert S, Lequang T, Maitre P, Poujol L, Cachon T, Carozzo C, et al. Sensitivity and specificity to determine lameness in dogs with a pressure walkway system. *Comput Methods Biomech Biomed Engin*. (2010) 13:61–2. doi: 10.1080/10255842.2010.493724

22. Light VA, Steiss JE, Montgomery RD, Rumph PF, Wright JC. Temporal-spatial gait analysis by use of a portable walkway system in healthy Labrador retrievers at a walk. *Am J Vet Res*. (2010) 71:997–1002. doi: 10.2460/ajvr.71.9.997

23. Kim J, Kazmierczak KA, Breur GJ. Comparison of temporospatial and kinetic variables of walking in small and large dogs on a pressure-sensing walkway. *Am J Vet Res*. (2011) 72:1171–7. doi: 10.2460/ajvr.72.9.1171

24. Strasser T, Peham C, Bockstahler BA. A comparison of ground reaction forces during level and cross-slope walking in Labrador retrievers. *BMC Vet Res*. (2014) 10:241. doi: 10.1186/s12917-014-0241-4

25. Lima CG, da Costa RC, Foss KD, Allen MJ. Temporospatial and kinetic gait variables of Doberman pinschers with and without cervical spondylomyelopathy. *Am J Vet Res*. (2015) 76:848–52. doi: 10.2460/ajvr.76.10.848

26. Keebaugh AE, Redman-Bentley D, Griffon DJ. Influence of leash side and handlers on pressure mat analysis of gait characteristics in small-breed dogs. *J Am Vet Med Assoc*. (2015) 246:1215–21. doi: 10.2460/javma.246.11.1215

27. Aristizabal Escobar AS, de Souza ANA, de Campos Fonseca Pinto ACB, Matera JM. Kinetic gait analysis in English bulldogs. *Acta Vet Scand*. (2017) 59:77. doi: 10.1186/s13028-017-0344-6

28. Besancon MF, Conzemius MG, Derrick TR, Ritter MJ. Comparison of vertical forces in normal greyhounds between force platform and pressure walkway measurement systems. *Vet Comp Orthop Traumatol*. (2003) 16:153–7. doi: 10.1055/s-0038-1632766

29. Pogue J, Zink C, Kieves NR. Effects of jump height on forelimb landing forces in border collies. *Front Vet Sci*. (2022) 9:1006990. doi: 10.3389/fvets.2022.1006990

30. Pfau T, Garland de Rivaz A, Brighton S, Weller R. Kinetics of jump landing in agility dogs. *Vet J*. (2011) 190:278–83. doi: 10.1016/j.tvjl.2010.10.008

31. Alvarez LX, Fox PR, Van Dyke JB, Grigsby P. Survey of referring veterinarians' perceptions of and reasons for referring patients to rehabilitation facilities. *J Am Vet Med Assoc*. (2016) 249:807–13. doi: 10.2460/javma.249.7.807

32. Alvarez LX, Repac JA, Kirkby Shaw K, Compton N. Systematic review of postoperative rehabilitation interventions after cranial cruciate ligament surgery in dogs. *Vet Surg*. (2022) 51:233–43. doi: 10.1111/vsu.13755

33. Millis DL, Ciuperca IA. Evidence for canine rehabilitation and physical therapy. *Vet Clin North Am Small Anim Pract*. (2015) 45:1–27. doi: 10.1016/j.cvsm.2014.09.001

34. Drum MG, Marcellin-Little DJ, Davis MS. Principles and applications of therapeutic exercises for small animals. *Vet Clin North Am Small Anim Pract*. (2015) 45:73–90. doi: 10.1016/j.cvsm.2014.09.005

35. Henderson AL, Latimer C, Millis DL. Rehabilitation and physical therapy for selected orthopedic conditions in veterinary patients. *Vet Clin North Am Small Anim Pract*. (2015) 45:91–121. doi: 10.1016/j.cvsm.2014.09.006

36. Flaherty MJ. Therapy exercises following cranial cruciate ligament repair in dogs. *Vet Clin North Am Small Anim Pract*. (2023) 53:857–68. doi: 10.1016/j.cvsm.2023.02.013

37. Zink C, Van Dyke JB. Canine sports medicine and rehabilitation. *2nd* ed. Hoboken, NJ: John Wiley and Sons, Inc. (2018).

38. Bockstahler B, Levine D, Maierl J, Millis D, Wittek K. Essential facts of physical medicine, rehabilitation and sports medicine in companion animals. *1st* ed. Munich, Germany: VBS GmbH (2019).

39. Gamble LJ. Physical rehabilitation for small animals. *Vet Clin North Am Small Anim Pract*. (2022) 52:997–1019. doi: 10.1016/j.cvsm.2022.03.005

40. Brown JA, Tomlinson J. Rehabilitation of the canine forelimb. *Vet Clin North Am Small Anim Pract*. (2021) 51:401–20. doi: 10.1016/j.cvsm.2020.12.005

41. Sparrow WA, Shinkfield A, Chow S, Begg RK. Characteristics of gait in stepping over obstacles. *Hum Mov Sci*. (1996) 15:605–22. doi: 10.1016/0167-9457(96)00022-X

42. Begg RK, Sparrow WA, Lythgo ND. Time-domain analysis of foot-ground reaction forces in negotiating obstacles. *Gait Posture*. (1998) 7:99–109. doi: 10.1016/s0966-6362(97)00039-8

43. Chen HL, Lu TW, Wang TM, Huang SC. Biomechanical strategies for successful obstacle crossing with the trailing limb in older adults with medial compartment knee osteoarthritis. *J Biomech*. (2008) 41:753–61. doi: 10.1016/j.jbiomech.2007.11.017

44. Lu TW, Chen HL, Wang TM. Obstacle crossing in older adults with medial compartment knee osteoarthritis. *Gait Posture*. (2007) 26:553–9. doi: 10.1016/j.gaitpost.2006.12.002

45. Caetano MJ, Lord SR, Schoene D, Pelicioni PH, Sturnieks DL, Menant JC. Age-related changes in gait adaptability in response to unpredictable obstacles and stepping targets. *Gait Posture*. (2016) 46:35–41. doi: 10.1016/j.gaitpost.2016.02.003

46. Desrochers PC, Kim D, Keegan L, Gill SV. Association between the functional gait assessment and spatiotemporal gait parameters in individuals with obesity compared to normal weight controls: a proof-of-concept study. *J Musculoskelet Neuronal Interact*. (2021) 21:335–42.

47. Lu TW, Chen HL, Chen SC. Comparisons of the lower limb kinematics between young and older adults when crossing obstacles of different heights. *Gait Posture*. (2006) 23:471–9. doi: 10.1016/j.gaitpost.2005.06.005

48. Chou LS, Draganich LF. Increasing obstacle height and decreasing toe-obstacle distance affect the joint moments of the stance limb differently when stepping over an obstacle. *Gait Posture*. (1998) 8:186–204. doi: 10.1016/s0966-6362(98)00034-4

49. Sato Y, Aoki S, Yanagihara D. Gait modification during approach phase when stepping over an obstacle in rats. *Neurosci Res*. (2012) 72:263–9. doi: 10.1016/j.neures.2011.11.008

50. Aoki S, Sato Y, Yanagihara D. Characteristics of leading forelimb movements for obstacle avoidance during locomotion in rats. *Neurosci Res*. (2012) 74:129–37. doi: 10.1016/j.neures.2012.07.007

51. Chu KMI, Seto SH, Beloozerova IN, Marlinski V. Strategies for obstacle avoidance during walking in the cat. *J Neurophysiol*. (2017) 118:817–31. doi: 10.1152/jn.00033.2017

52. Bovonsunthonchai S, Khobkhun F, Vachalathiti R. Ground reaction forces of the Lead and trail limbs when stepping over an obstacle. *Med Sci Monit*. (2015) 21:2041–9. doi: 10.12659/MSM.893965

53. Clayton HM, Barlow DA. The effect of fence height and width on the limb placements of show jumping horses. *J Equine Vet*. (1989) 9:179–85. doi: 10.1016/S0737-0806(89)80046-2

54. Leach DH, Ormrod K, Clayton HM. Stride characteristics of horses competing in grand prix jumping. *Am J Vet Res*. (1984) 45:888–92.

55. Birch E, Carter A, Boyd J. An examination of jump kinematics in dogs over increasing hurdle heights. *Comp Exer Phys*. (2016) 12:91–8. doi: 10.3920/CEP150037

56. Birch E, Leśniak K. Effect of fence height on joint angles of agility dogs. *Vet J*. (2013) 198:e99–e102. doi: 10.1016/j.tvjl.2013.09.041

57. Birch E, Boyd J, Doyle G, Pullen A. The effects of altered distances between obstacles on the jump kinematics and apparent joint angulations of large agility dogs. *Vet J*. (2015) 204:174–8. doi: 10.1016/j.tvjl.2015.02.019

58. Bockstahler BA, Prickler B, Lewy E, Holler PJ, Vobornik A, Peham C. Hind limb kinematics during therapeutic exercises in dogs with osteoarthritis of the hip joints. *Am J Vet Res*. (2012) 73:1371–6. doi: 10.2460/ajvr.73.9.1371

59. Breitfuss K, Franz M, Peham C, Bockstahler B. Surface electromyography of the vastus Lateralis, biceps Femoris, and gluteus Medius muscle in sound dogs during walking and specific physiotherapeutic exercises. *Vet Surg*. (2015) 44:588–95. doi: 10.1111/j.1532-950X.2014.12302.x

60. McLean H, Millis D, Levine D. Surface electromyography of the vastus Lateralis, biceps Femoris, and gluteus Medius in dogs during stance, walking, trotting, and selected therapeutic exercises. *Front Vet Sci*. (2019) 6:211. doi: 10.3389/fvets.2019.00211

61. Holler PJ, Brazda V, Dal-Bianco B, Lewy E, Mueller MC, Peham C, et al. Kinematic motion analysis of the joints of the forelimbs and hind limbs of dogs during walking exercise regimens. *Am J Vet Res*. (2010) 71:734–40. doi: 10.2460/ajvr.71.7.734

62. Charalambous D, Strasser T, Tichy A, Bockstahler B. Ground reaction forces and Center of Pressure within the paws when stepping over obstacles in dogs. *Animals (Basel)*. (2022) 12:1702. doi: 10.3390/ani12131702

63. McLaughlin RM Jr, Roush JK. Effects of subject stance time and velocity on ground reaction forces in clinically normal greyhounds at the trot. *Am J Vet Res*. (1994) 55:1666–71. doi: 10.2460/ajvr.1994.55.12.1666

64. McLaughlin RM Jr, Gaughan EM, Roush JK, Skaggs CL. Effects of subject velocity on ground reaction force measurements and stance times in clinically normal horses at the walk and trot. *Am J Vet Res*. (1996) 57:7–11. doi: 10.2460/ajvr.1996.57.01.7

65. Roush JK, McLaughlin RM Jr. Effects of subject stance time and velocity on ground reaction forces in clinically normal greyhounds at the walk. *Am J Vet Res*. (1994) 55:1672–6. doi: 10.2460/ajvr.1994.55.12.1672

66. Riggs CM, DeCamp CE, Soutas-Little RW, Braden TD, Richter MA. Effects of subject velocity on force plate-measured ground reaction forces in healthy greyhounds at the trot. *Am J Vet Res*. (1993) 54:1523–6. doi: 10.2460/ajvr.1993.54.09.1523

67. Jones GMC, Pitsillides AA, Meeson RL. Moving beyond the limits of detection: the past, the present, and the future of diagnostic imaging in canine osteoarthritis. *Front Vet Sci*. (2022) 9:789898. doi: 10.3389/fvets.2022.789898

68. Olsson SE. Degenerative joint disease (osteoarthrosis): a review with special reference to the dog. *J Small Anim Pract*. (1971) 12:333–42. doi: 10.1111/j.1748-5827.1971.tb06238.x

69. Gordon WJ, Conzemius MG, Riedesel E, Besancon MF, Evans R, Wilke V, et al. The relationship between limb function and radiographic osteoarthrosis in dogs with stifle osteoarthrosis. *Vet Surg*. (2003) 32:451–4. doi: 10.1053/jvet.2003.50051

70. Morgan JP, Voss K, Damur DM, Guerrero T, Haessig M, Montavon PM. Correlation of radiographic changes after tibial tuberosity advancement in dogs with cranial cruciate-deficient stifles with functional outcome. *Vet Surg*. (2010) 39:425–32. doi: 10.1111/j.1532-950X.2010.00669.x

71. Hielm-Björkman AK, Kuusela E, Liman A, Markkola A, Saarto E, Huttunen P, et al. Evaluation of methods for assessment of pain associated with chronic osteoarthritis in dogs. *J Am Vet Med Assoc*. (2003) 222:1552–8. doi: 10.2460/javma.2003.222.1552

72. Innes JF, Costello M, Barr FJ, Rudorf H, Barr AR. Radiographic progression of osteoarthritis of the canine stifle joint: a prospective study. *Vet Radiol Ultrasound*. (2004) 45:143–8. doi: 10.1111/j.1740-8261.2004.04024.x

73. Dennis R. Interpretation and use of BVA/KC hip scores in dogs. *In Pract*. (2012) 34:178–94. doi: 10.1136/inp.e2270

frontiers | Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 01 August 2024
DOI 10.3389/fvets.2024.1431843

Check for updates

OPEN ACCESS

EDITED BY
David Levine,
University of Tennessee at Chattanooga, United States

REVIEWED BY
Tanya C. Garcia,
University of California, Davis, United States
Hannah McLean,
McLean Veterinary Sports Medicine, United States
Matthew Warren Brunke,
Veterinary Referral Associates, United States

*CORRESPONDENCE
John A. Schwartz
✉ schwartzjohn@ufl.edu

RECEIVED 13 May 2024
ACCEPTED 24 July 2024
PUBLISHED 01 August 2024

CITATION
Schwartz JA, Carrera-Justiz S and Repac JA (2024) Surface electromyography of the vastus lateralis and gluteus medius muscles in post-operative T3–L3 hemilaminectomy dogs: a prospective controlled observational study.
Front. Vet. Sci. 11:1431843.
doi: 10.3389/fvets.2024.1431843

Surface electromyography of the vastus lateralis and gluteus medius muscles in post-operative T3–L3 hemilaminectomy dogs: a prospective controlled observational study

John A. Schwartz[1]*, Sheila Carrera-Justiz[2] and Jennifer A. Repac[1]

[1]Department of Comparative, Diagnostic & Population Medicine, College of Veterinary Medicine, University of Florida, Gainesville, FL, United States, [2]Department of Small Animal Clinical Science, College of Veterinary Medicine, University of Florida, Gainesville, FL, United States

Objective: The objective of this study was to determine if surface electromyography (sEMG) demonstrates differences in muscle activation between normal and dogs recovering from spinal cord injury due to intervertebral disk extrusion.

Animals: Two groups of client-owned small-breed chondrodysplastic-type dogs were tested. Group 1 consisted of seven ambulatory paraparetic dogs that had undergone a hemilaminectomy procedure in the T3-L3 region for intervertebral disk extrusion 1 month prior. Group 2 was made up of seven normal dogs that had no history of intervertebral disk disease or spinal surgery.

Procedures: Each subject walked 10 feet on a nonslip surface for at least five gait cycles for the sEMG to capture muscle activation of the vastus lateralis and gluteus medius, bilaterally. Muscle activation was quantified as the total myoelectric output area under the curve, averaged across all gait cycles.

Results: Muscle activation was significantly greater in the post-operative hemilaminectomy group ($p = 0.012$). There was a significant difference in muscle activation between each hindlimb in the post-operative hemilaminectomy group, but not in the normal group. The muscle activation was significantly lower on the side that underwent surgery compared to the opposite limb ($p = 0.0034$).

Conclusion and clinical importance: Post-operative hemilaminectomy dogs have greater hindlimb muscle activation compared to normal dogs, which likely represents a lack of descending inhibition secondary to upper motor neuron syndrome. The side of surgery is correlated with decreased muscle activation. Surface EMG can be used to evaluate muscle activity in dogs recovering from spinal decompression surgery.

KEYWORDS

rehabilitation, physical therapy, sports medicine, neurology, spinal cord injury

Introduction

Intervertebral disk disease (IVDD) is the most common spinal disorder and the leading cause of acute paralysis in dogs (1). Chondrodystrophic breeds are overrepresented, with Miniature and Standard Dachshunds most affected (2, 3). Currently, paresis is mainly evaluated through the use of observational gait scoring systems.

The most commonly utilized neurologic scoring system, Modified Frankel Scoring (MFS), differentiates dogs into five categories based on the presence of motor, sensation, and ambulation status (Figure 1) (4–6). However, this scoring system fails to take into account the more subtle nuances of patient recovery. Dogs with a grade 2 or 3 MFS can have a wide range of motor function that is not conveyed by the scoring system. The American Spinal Injury Association (ASIA) impairment scale (AIS) is used in humans to evaluate functional impairment due to spinal cord injury (SCI). The scale includes tests not feasible to conduct in dogs because they require voluntary movement and verbal responses to stimuli (7).

Surface electromyography (sEMG) is a non-invasive technology that is used to measure muscle activity and myoelectric output. It offers an objective measure of neuromuscular function. Previous studies have used surface sEMG to measure muscle activity in normal dogs and dogs with orthopedic conditions such as hip osteoarthritis and cranial cruciate ligament rupture (8–10). Thus far, sEMG has not been used to evaluate neurological canine patients.

Surface EMG is well-established inhuman literature as a technology used in clinical rehabilitation, especially in people with spinal cord injuries (11). The only research that has evaluated muscle activity in dogs with myelopathies has used more invasive needle EMG technology in anesthetized patients (12, 13). No research has been performed using sEMG to measure muscle activity in dogs with myelopathies following hemilaminectomy. The objective of this study was to determine if sEMG demonstrates differences in muscle activation between normal and dogs recovering from intervertebral disk extrusion (IVDE). We hypothesize that the muscle activation pattern will be different in dogs 1-month post-operative thoracolumbar hemilaminectomy compared to normal dogs during walking.

Modfied Frankel Score	Neurological Description
Grade 1	No neurological dysfunction with spinal hyperesthesia
Grade 2	Ambulatory paraparesis
Grade 3	Non-ambulatory paraparesis
Grade 4	Paraplegia with intact nociception in pelvic limbs and/or tail
Grade 5	Paraplegia with absent nociception in pelvic limbs and/or tail

FIGURE 1
Modified Frankel score, used to described neurologic dysfunction.

Materials and methods

Two groups of client-owned small-breed chondrodysplastic-type dogs weighing up to 20 kilograms were tested (Table 1). Group 1 was comprised of seven ambulatory paraparetic dogs that had a history of intervertebral disk extrusion with a hemilaminectomy procedure in the T3-L3 region that was performed 1 month prior. Group 2 was made up of seven dogs that had no history of intervertebral disk disease or spinal surgery with normal neurological and orthopedic examinations. The inclusion and exclusion criteria of each respective group was as follows:

Group 1 (Post-hemilaminectomy, $n = 7$) inclusion criteria:

- Ambulatory paraparesis
- Chondrodysplastic breeds
- Weighing up to 20 kg
- Body condition score of 5/9 and muscle condition score of 3/3
- Dogs with a history of intervertebral disk extrusion with history of hemilaminectomy in the T3-L3 region, performed 4–6 weeks prior.
- Normal orthopedic exam
- Dogs with no other evidence of disk extrusion in other spinal segments.

Group 2 (Control dogs, $n = 7$) inclusion criteria:

- Chondrodysplastic breeds
- Weighing up to 20 kg
- Body condition score of 5/9 and muscle condition score of 3/3
- Normal neurological and orthopedic exam
- No history of IVDD or spinal surgery

Exclusion criteria for both groups:

- Orthopedic abnormalities
- Other concurrent spinal cord or neurologic disease
- Dermatologic conditions that interfere with sensor placement
- Temperament not conducive to sensor placement
- Serious comorbidities or medication (e.g., anti-epileptic drugs, glucocorticoids) that may affect mobility

All animals were assessed by a board-certified Neurologist or neurology resident for a neurological examination and a board-certified Sports Medicine and Rehabilitation specialist for an orthopedic examination prior to study enrolment. During the same visit, a telemetric unit (Myomotion; Noraxon United States, Inc., Scottsdale, AZ) was used to measure muscle activity. The disposable self-adhesive dual electrodes with low impedance solid gel (2 cm

TABLE 1 Demographic data; group 1 (control group) and group 2 (post-op hemilaminectomy).

	Patient	Breed	Age (years)	Sex	Weight (kg)	Surgery	MFS grade
Group 1							
	1	Miniature Dachshund	8	M	7.6	n/a	n/a
	2	Miniature Dachshund	3	F	4.2	n/a	n/a
	3	Chihuahua Mix	4	M	4.8	n/a	n/a
	4	French Bulldog	1	M	15.7	n/a	n/a
	5	Miniature Dachshund	8	M	7.6	n/a	n/a
	6	Chihuahua Mix	5	F	6.8	n/a	n/a
	7	Miniature Dachshund	8	M	7.3	n/a	n/a
Group 2							
	8	Chihuahua	10	M	6.1	Right T11-T12	2
	9	Havanese mix	3	F	6.2	Right T11-T12	2
	10	Miniature Dachshund	11	M	5.0	Left L1-L2	2
	11	French Bulldog	5	M	18.2	Right T13-L1	2
	12	Papillon	8	M	4.7	Right T13-L1	2
	13	Chihuahua Mix	6	M	16.0	Right T11-T12	2
	14	Miniature Dachshund	5	F	4.9	Right T11-T12	2

spacing) and sensors were applied and positioned using adhesive barrier wipes (Skin-Tac™; Torbot Group Inc., Toledo, OH) to clean and shaven skin over the vastus lateralis and gluteus medius muscles, bilaterally as previously described (Figure 2) (9). Each subject was leash-walked with a slip lead or encouraged to walk toward an investigator at a comfortable walking pace over a marked 10 ft. nonslip surface for the sEMG to capture muscle activation over five gait cycles within the defined distance. The data were processed and smoothed to remove noise using an infinite impulse response (IIR) bidirectional lowpass Butterworth filter (<50 Hz and > 450 Hz) (14–16). Data were normalized to the peak amplitude within each animal's gait cycle using a 500 ms window. The total sEMG burst area was calculated by adding up all points within the burst after subtracting the background sEMG and then averaged across all gait cycles to create a mean area under the curve as a percentage of muscle activation.

FIGURE 2
The position of the dual electrodes and sensors over the left vastus lateralis and gluteus medius muscles.

Statistics

Statistical analysis was performed using JMP®, Version 17 (SAS Institute Inc., Cary, NC). A linear mixed model was used to analyze the data with the patient as a random effect and surgical side, muscle, and their interaction as fixed effects. Model assumptions, normality, and constant variance were checked via inspection of model residuals. Tukey's multiple comparison procedure was used to test for pairwise mean comparisons. A linear contrast was used to test for overall differences between surgical groups. A p-value < 0.05 was considered statistically significant. Based on previous studies, we predicted mean muscle activation would have a standard deviation of 0.95 and the correlation between normal and post-operative dogs would be 0.5 (8). Based on our parameter choices, we used 14 participants for a desired power of 0.90 and a Type I error rate of 0.05.

Results

The age, sex, MFS, surgical location, and body weight of all dogs of the post-hemilaminectomy dogs are described in Table 1. There were no statistically significant differences between the two groups with respect to age, sex, and weight ($p > 0.05$). Muscle activity was significantly greater in the hemilaminectomy group ($p = 0.012$) compared to the normal group (Figure 3; Table 2). A significant difference was also seen between each hindlimb within the post-operative group. The sum of the combined muscle activity was significantly greater in the contralateral limb opposite the limb on the surgical ($p = 0.0034$; Figure 4). There were no significant differences in muscle activity between the different muscle groups.

Discussion

The use of sEMG is a widely accepted outcome measure in both human spinal cord injury research and clinical physical rehabilitation (17). In veterinary literature, previous studies have been primarily focused on using sEMG to measure muscle activity in normal dogs and in dogs with orthopedic conditions, but never those affected by neurologic disease.

This study found significantly greater muscle activation in the post-op hemilaminectomy compared to the control group. Thus, our hypothesis that the muscle activation pattern will be different in dogs one-month post-operative thoracolumbar hemilaminectomy compared to normal dogs during walking was supported. However, we initially expected that the post-op hemilaminectomy group would have decreased muscle activity due to paresis.

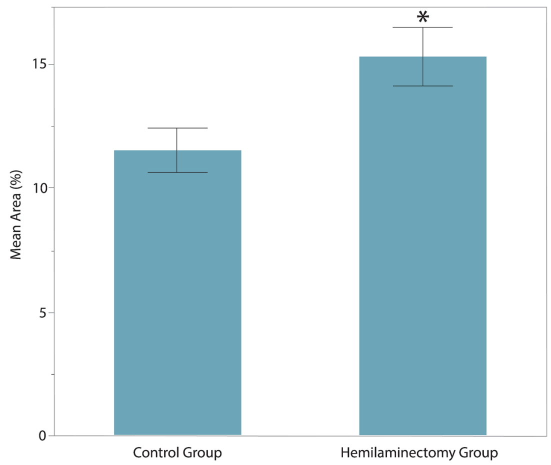

FIGURE 3
Muscle activity of vastus lateralis and gluteus medius between control group and post-operative hemilaminectomy group. The hemilaminectomy group had significantly greater muscle activity (15.34 ± 2.41%) than the control group (11.52 ± 2.43%, *represents significance at $p = 0.012$).

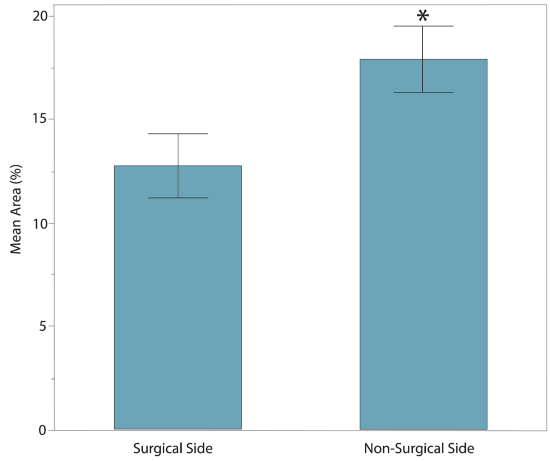

FIGURE 4
The sum of combined muscle activity between each hindlimb within the post-operative hemilaminectomy group. The muscle activity was significantly greater in the limb on the non-surgical side (17.92 ± 4.45%) compared to the post-hemilaminectomy group (12.77 ± 4.67%, *represents significance at $p = 0.0034$).

TABLE 2 Mean area and standard deviation of muscle activation; group 1 (control group) and group 2 (post-op hemilaminectomy).

	Patient	Total Mean ± SD	Left Hindlimb Mean	Right Hindlimb Mean
Group 1				
	1	9.45 ± 3.88%	12.25 ± 2.05	6.65 ± 3.10
	2	9.46 ± 8.36%	8.15 ± 8.00	10.77 ± 11.79
	3	11.65 ± 2.67%	12.48 ± 3.85	10.83 ± 1.94
	4	11.55 ± 1.80%	11.40 ± 2.69	11.70 ± 1.60
	5	10.33 ± 0.29%	10.55 ± 0.21	10.10 ± 0
	6	16.55 ± 5.27%	15.25 ± 0.92	17.85 ± 8.70
	7	11.66 ± 6.36%	12.00 ± 1.70	11.32 ± 10.87
Group 2	Patient	Total Mean ± SD	Surgical Side Mean	Non-Surgical Side Mean
	8	13.94 ± 12.56%	3.08 ± 0.76%	24.80 ± 01.13%
	9	12.16 ± 2.17%	11.11 ± 1.82%	13.20 ± 2.55%
	10	13.65 ± 2.28%	13.60 ± 3.68%	13.70 ± 1.14%
	11	17.13 ± 5.09%	15.10 ± 7.21%	19.15 ± 3.04%
	12	18.26 ± 5.92%	14.62 ± 7.19%	21.90 ± 0.42%
	13	17.98 ± 7.71%	17.45 ± 3.46%	18.52 ± 12.82%
	14	14.30 ± 4.69%	14.40 ± 5.37%	14.19 ± 6.10%

Dogs with intervertebral disk extrusions (IVDE) in the T3-L3 spinal cord segment typically display signs of upper motor neuron (UMN) syndrome. This consists of paresis, ataxia, and spasticity in the hindlimbs. The UMN pathways inhibit both the extensor and flexor muscles. However, most T3-L3 lesions that affect these pathways release the extensor motor neurons from inhibition, resulting in hypertonia (18). The increase in muscle activity can cause paresis and ataxia because the normal inhibition of these muscles is what results in a smooth and regulated gait. The greater muscle activity in the post-op hemilaminectomy group may be explained by this hypertonia.

Within the post-op hemilaminectomy group, there was also significantly less muscle activation in the limb on the surgical side compared to the non-surgical side. The laterality of the surgical decompression is determined based on the side with the greatest spinal cord compression. For this reason, dogs are usually more paretic on the same side as the surgical site. That the increased muscle activity of the limb on the non-surgical side is due to a combination of increased UMN spasticity and increased voluntary motor function. Human medical literature shows that patients with SCI can experience increased muscle activity due to spasticity. For example, in studies using sEMG, involuntary muscle activity at rest was found to be significantly higher in SCI participants compared to able-bodied control participants (17). Additionally, using sEMG has been shown to measure reflex hyperexcitability and determine the occurrence of muscle spasms in individuals with SCI (19, 20).

This study had limitations due to the sample size and the patient population we used. Although a power analysis was performed, the sample size remained relatively limited. It was also challenging to fit sEMG sensors and electrodes on the hindlimbs of chondrodysplastic dogs weighing less than 20 kg. This is why sensors were placed on only two muscles (vastus lateralis and gluteus medius muscles), compared to previous studies, which also include the biceps femoris. Previous studies have typically used larger breed dogs, such as Labrador Retrievers, Golden Retrievers, Weimaraners, and shepherds (8, 9, 14, 21). Chondrodystrophic dogs were selected for this study because they are most representative of the population undergoing hemilaminectomies. In addition to smaller anatomy, variations in body condition and skin movement can make it difficult to isolate individual muscle activity (22, 23). In humans, it has been shown that increased body fat and body mass index can contribute to a lower recording of bioelectrical activity when using sEMG (24). Surface EMG cannot measure the activity of deep muscles so it is not as precise as conventional EMG, which uses a needle that can be placed into the exact muscle body of interest. This is why all the patients included in this study had to have an ideal body condition score of 5/9 and a normal muscle condition score of 3/3.

In human sEMG studies, data is normalized to a maximum voluntary contraction, which helps define muscle activity as a percentage of that maximum value (14). This cannot be performed in dogs, so a maximum dynamic contraction is used instead as a baseline by having a dog perform a high-intensity exercise (25). Because our patient population was recovering from hemilaminectomy surgery and still had neurological deficits, a maximum dynamic contraction could not be used to normalize the data. Instead, we measured the muscle burst duration as an area under the curve as a percent during the gait cycle to obtain the muscle activity values (26).

While sEMG is non-invasive and relatively user-friendly, EMG overall has several limitations. A significant drawback is the requirement for isometric contractions to establish a reliable quantitative relationship between EMG signals and muscle force (27). Non-linearities and signal non-stationarities are introduced by anisometric contractions, which can complicate analysis and interpretation. Additionally, intrinsic anatomical and physiological factors, such as the number of active motor units, their proximity to the electrode, the detection volume of the electrode, and the presence of subcutaneous tissue, can influence the EMG signal's amplitude. The interpretation of the EMG signal is further complicated by crosstalk from nearby muscles and the instability of motor unit activation patterns during dynamic contractions (27).

Future studies could potentially use scales such as the Ashworth or Olby scales to better understand the relationship between muscle activity and clinical status of disease than the more simplified MFS that was used in this study. The Modified Ashworth Scale is the predominant clinical measure utilized to evaluate muscle spasticity in human patients diagnosed with neurological conditions. The scale assesses resistance experienced during passive range of motion and is used to evaluate the efficacy of pharmacologic and physical rehabilitation interventions (28). The Olby scale is a 14-point SCI grading scale that was validated in dogs to assess neurological function following spinal cord injury (29). It evaluates voluntary movement, muscle tone, and sensation to accurately quantify the extent of recovery in dogs following SCI.

Compared to human medicine, there is less research and validation of sEMG techniques in veterinary medicine (30). This is mainly due to the lack of standardized protocols, reference values, and established clinical applications. Widely available sEMG systems are also typically designed for human use, which can make it difficult for veterinary-specific applications. Though additional research is needed, this study has shown that sEMG can be used to measure muscle activity in ambulatory paraparetic dogs following SCI.

Conclusion

Surface EMG can be used to evaluate muscle activity in dogs recovering from T3-L3 IVDE. There is greater muscle activity in dogs that have undergone hemilaminectomy surgery compared to normal dogs. This increase is most likely due to hypertonia resulting from UMN syndrome. To gage the recovery progress of dogs who have undergone spinal decompression surgery, research is needed to determine whether sEMG can be employed as an effective prognostic indicator for dogs recovering from a T3-L3 myelopathy due to IVDE.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal studies were approved by University of Florida's Institutional Animal Care & Use Committee and Veterinary Hospitals

Research Review Committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

JS: Data curation, Formal analysis, Funding acquisition, Investigation, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. SC-J: Supervision, Writing – review & editing, Methodology. JR: Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing, Visualization.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. 2021 Purina and American Association of Rehabilitation Veterinarians Grant Award Winner.

Acknowledgments

We thank James Colee, MS, of the University of Florida's Statistical Consulting Unit Institute of Food and Agricultural Sciences for statistical analysis.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Rossi G, Stachel A, Lynch AM, Olby NJ. Intervertebral disc disease and aortic thromboembolism are the most common causes of acute paralysis in dogs and cats presenting to an emergency clinic. *Vet Rec*. (2020) 187:e81–1. doi: 10.1136/vr.105844

2. Bergknut N, Egenvall A, Hagman R, Gustås P, Hazewinkel HAW, Meij BP, et al. Incidence of intervertebral disk degeneration–related diseases and associated mortality rates in dogs. *J Am Vet Med Assoc*. (2012) 240:1300–9. doi: 10.2460/javma.240.11.1300

3. Smolders LA, Bergknut N, Grinwis GC, Hagman R, Lagerstedt AS, Hazewinkel HA, et al. Intervertebral disc degeneration in the dog. Part 2: Chondrodystrophic and non-chondrodystrophic breeds. *Vet J*. (2013) 195:292–9. doi: 10.1016/j.tvjl.2012.10.011

4. Frankel HL, Hancock DO, Hyslop G, Melzak J, Michaelis LS, Ungar GH, et al. The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. *Spinal Cord*. (1969) 7:179–92. doi: 10.1038/sc.1969.30

5. Scott HW. Hemilaminectomy for the treatment of thoracolumbar disc disease in the dog: a follow-up studv of 40 cases. *J Small Anim Pract*. (1997) 38:488–94. doi: 10.1111/j.1748-5827.1997.tb03303.x

6. van Wie E, Fosgate GT, Mankin JM, Jeffery ND, Kerwin SC, Levine GJ, et al. Prospectively recorded versus medical record-derived spinal cord injury scores in dogs with intervertebral disk herniation. *J Vet Intern Med*. (2013) 27:1273–7. doi: 10.1111/jvim.12149

7. American Spinal Injury Association. Worksheet international standards for neurological classification of spinal cord injury (ISNCSCI); Revised version (2015). Available from: http://asia-spinalinjury.org/information/downloads/. Accessed March 2018.

8. McLean H, Millis D, Levine D. Surface electromyography of the Vastus Lateralis, biceps Femoris, and gluteus Medius in dogs during stance, walking, trotting, and selected therapeutic exercises. *Front Vet Sci*. (2019) 6:211. doi: 10.3389/fvets.2019.00211

9. Bockstahler B, Kräutler C, Holler P, Kotschwar A, Vobornik A, Peham C. Pelvic limb kinematics and surface electromyography of the vastus lateralis, biceps femoris, and gluteus medius muscle in dogs with hip osteoarthritis. *Vet Surg*. (2012) 41:54–62. doi: 10.1111/j.1532-950X.2011.00932.x

10. Adrian CP, Haussler KK, Kawcak CE, Reiser RF II, Riegger-Krugh C, Palmer RH, et al. Gait and electromyographic alterations due to early onset of injury and eventual rupture of the cranial cruciate ligament in dogs: a pilot study. *Vet Surg*. (2019) 48:388–400. doi: 10.1111/vsu.13178

11. Pilkar R, Momeni K, Ramanujam A, Ravi M, Garbarini E, Forrest GF. Use of surface EMG in clinical rehabilitation of individuals with sci: barriers and future considerations. *Front Neurol*. (2020) 11:11. doi: 10.3389/fneur.2020.578559

12. De Decker S, Gielen IM, Duchateau L, Oevermann A, Polis I, Van Soens I, et al. Evolution of clinical signs and predictors of outcome after conservative medical treatment for disk-associated cervical spondylomyelopathy in dogs. *J Am Vet Med Assoc*. (2012) 240:848–57. doi: 10.2460/javma.240.7.848

13. Siedenburg JS, Wang-Leandro A, Amendt HL, Rohn K, Tipold A, Stein VM. Transcranial magnetic motor evoked potentials and magnetic resonance imaging findings in paraplegic dogs with recovery of motor function. *J Vet Intern Med*. (2018) 32:1116–25. doi: 10.1111/jvim.15058

14. Parkinson S, Wills AP, Tabor G, Williams JM. Effect of water depth on muscle activity of dogs when walking on a water treadmill. *Comparative Exercise Physiol*. (2018) 14:79–89. doi: 10.3920/CEP170031

15. St George L, Roy SH, Richards J, Sinclair J, Hobbs SJ. Surface EMG signal normalisation and filtering improves sensitivity of equine gait analysis. *Cephalalgia*. (2019) 15:173–86. doi: 10.3920/CEP190028

16. Spoormakers TJP, St George L, Smit IH, Hobbs SJ, Brommer H, Clayton HM, et al. Adaptations in equine axial movement and muscle activity occur during induced fore-and hindlimb lameness: a kinematic and electromyographic evaluation during in-hand trot. *Equine Vet J*. (2023) 55:1112–27. doi: 10.1111/evj.13906

17. Balbinot G, Li G, Wiest MJ, Pakosh M, Furlan JC, Kalsi-Ryan S, et al. Properties of the surface electromyogram following traumatic spinal cord injury: a scoping review. *J Neuroeng Rehabil*. (2021) 18:105. doi: 10.1186/s12984-021-00888-2

18. DeLahunta A, Glass E, Kent M. ed. De Lahunta's veterinary neuroanatomy and clinical neurology. 5th ed. Philadelphia: Elsevier (2021).

19. Thomas CK, Dididze M, Martinez A, Morris RW. Identification and classification of involuntary leg muscle contractions in electromyographic records from individuals with spinal cord injury. *J Electromyogr Kinesiol*. (2014) 24:747–54. doi: 10.1016/j.jelekin.2014.05.013

20. Winslow J, Martinez A, Thomas CK. Automatic identification and classification of muscle spasms in long-term EMG recordings. *IEEE J Biomed Health Inform*. (2015) 19:464–70. doi: 10.1109/JBHI.2014.2320633

21. Breitfuss K, Franz M, Peham C, Bockstahler B. Surface electromyography of the vastus lateralis, biceps femoris, and gluteus medius muscle in sound dogs during walking and specific physiotherapeutic exercises. *Vet Surg*. (2015) 44:588–95. doi: 10.1111/j.1532-950X.2014.12302.x

22. Petrofsky J. The effect of the subcutaneous fat on the transfer of current through skin and into muscle. *Med Eng Phys*. (2008) 30:1168–76. doi: 10.1016/j.medengphy.2008.02.009

23. Reinschmidt C, van den Bogert AJ, Nigg BM, Lundberg A, Murphy N. Effect of skin movement on the analysis of skeletal knee joint motion during running. *J Biomech*. (1997) 30:729–32. doi: 10.1016/S0021-9290(97)00001-8

24. Ptaszkowski K, Wlodarczyk P, Paprocka-Borowicz M. The relationship between the electromyographic activity of rectus and oblique abdominal muscles and bioimpedance body composition analysis - a pilot observational study. *Diabetes Metab Syndr Obes*. (2019) 12:2033–40. doi: 10.2147/DMSO.S215982

25. Halaki M, Gi K. Normalization of emg signals: to normalize or not to normalize and what to normalize to? In: Ganesh N, editor. Computational intelligence in electromyography analysis - a perspective on current applications and future challenges. InTech (2012)

26. Gorassini MA, Norton JA, Nevett-Duchcherer J, Roy FD, Yang JF. Changes in locomotor muscle activity after treadmill training in subjects with incomplete spinal cord injury. *J Neurophysiol*. (2009) 101:969–79. doi: 10.1152/jn.91131.2008

27. De Luca CJ. The use of surface electromyography in biomechanics. *J Appl Biomech*. (1997) 13:135–63. doi: 10.1123/jab.13.2.135

28. Meseguer-Henarejos AB, Sánchez-Meca J, López-Pina JA, Carles-Hernández R. Inter-and intra-rater reliability of the modified Ashworth scale: a systematic review and meta-analysis. *Eur J Phys Rehabil Med*. (2018) 54:576–90. doi: 10.23736/S1973-9087.17.04796-7

29. Olby NJ, De Risio L, Muñana KR, Wosar MA, Skeen TM, Sharp NJH, et al. Development of a functional scoring system in dogs with acute spinal cord injuries. *Am J Vet Res*. (2001) 62:1624–8. doi: 10.2460/ajvr.2001.62.1624

30. Valentin S, Zsoldos RR. Surface electromyography in animals: a systematic review. *J Electromyogr Kinesiol*. (2016) 28:167–83. doi: 10.1016/j.jelekin.2015.12.005

frontiers | Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 22 August 2024
DOI 10.3389/fvets.2024.1409199

Check for updates

OPEN ACCESS

EDITED BY
Christopher R. Byron,
Virginia Tech, United States

REVIEWED BY
Alison Wills,
Hartpury University and Hartpury College, United Kingdom
Michael Jaffe,
Mississippi State University, United States

*CORRESPONDENCE
Nina R. Kieves
Kieves.1@osu.edu

†PRESENT ADDRESS
Arielle Pechette Markley,
Red Sage Integrative Veterinary Partners,
Fort Collins, CO, United States

RECEIVED 29 March 2024
ACCEPTED 31 July 2024
PUBLISHED 22 August 2024

CITATION
Alva BM, Pechette Markley A, Shoben A and Kieves NR (2024) Owner-reported treatments and outcomes of perceived injuries to the thoracic and pelvic limb of agility dogs. *Front. Vet. Sci.* 11:1409199.
doi: 10.3389/fvets.2024.1409199

Owner-reported treatments and outcomes of perceived injuries to the thoracic and pelvic limb of agility dogs

Bianca M. Alva[1], Arielle Pechette Markley[2†], Abigail Shoben[3] and Nina R. Kieves[2*]

[1]VCA Animal Referral Center of Arizona, Mesa, AZ, United States, [2]Department of Veterinary Clinical Sciences, College of Veterinary Medicine, The Ohio State University, Columbus, OH, United States, [3]College of Public Heath, Division of Biostatistics, The Ohio State University, Columbus, OH, United States

Objective: The aim of this study was to identify the type of veterinary care sought by handlers of injured agility dogs, the types of treatments the dogs received, and the timeframe for return to training and competition.

Procedures: Owners of agility dogs completed an internet-based survey. They were instructed to report injuries that had kept the dog from training or competing for over a week, identify which area(s) of the body had been injured and answer questions about the most severe injury to each body part. Additional questions included if handlers had sought veterinary care, who primarily determined treatment, type of treatment(s), and length of time before the dog could return to full training and competition.

Results: This sample included data on 1,714 total injuries from 1,256 unique dogs. Handlers sought veterinary care for over 80% of injuries across all anatomical locations. Handlers were most likely to seek specialty veterinary care for reported injuries to the stifle (71%), iliopsoas (63%) and tibia (61%), and least likely for reported injuries to the carpus (34%), metatarsus (33%) and metacarpus (22%). Treatment of reported injuries to the antebrachium and stifle were most likely to be directed by a veterinarian (>70%), while reported injuries of the thigh (51%) and hip (53%) were least likely. Rest was the most common treatment for all injuries. Return to sport within 3 months was common (>67%) for most perceived injury locations, though dogs with reported stifle injuries took longer to return to competition and had a higher rate of retirement.

Conclusion and clinical relevance: Owners of agility dogs have a high rate of seeking veterinary care for injuries. Overall return to sport rates were high, with the stifle being the notable exception. Future studies regarding specific treatment of injuries in agility dogs, and how injuries and their treatment affect return to agility after injury are required to provide optimal care protocols for these canine athletes.

KEYWORDS

agility, dog, injury, thoracic limb, pelvic limb, treatment, outcome

1 Introduction

Canine agility is one of the most popular dog sports worldwide and participation has grown, with entries into sponsored events by the American Kennel Club increasing 38% from 2009 to 2019 (1). There has also been an increase in reported injuries in agility dogs, with an overall injury rate of 41.7% reported in 2019 compared to 32% reported the previous decade (2, 3). The increased injury rate, as well as the increasing participation in the sport, require refined knowledge of injury treatment and outcomes to provide the best care recommendations for these patients.

Numerous retrospective survey studies have reported on types of injuries reported by owners of agility dogs. These studies have shown that reported shoulder injuries are common, with back injuries also commonly reported (2–6). Reported overall return to competition timelines have varied from relatively quick resolution with 71% returning to agility in less than 4 weeks in one study (4) and 50% returning in less than 1 month in another (3), to relatively longer resolution with only 26% returning in less than 3 weeks and 33% taking longer than 8 weeks to return to competition (6). However, none of these studies have examined return to agility timelines by type of injury.

A handful of these studies have also provided limited information about treatment of injuries among agility dogs. The reported percentage of dogs being treated by any veterinarian varied from 41 to 78% (3, 4, 6). One previous study reported the frequency of various therapies among all injured agility dogs, but this information was not specific to the type of injury (6). Given the growth of sports medicine and rehabilitation as a veterinary specialty, as well as increased availability of additional treatment modalities such as orthobiologics, this study sought to characterize the types of professionals consulted, as well as the types of treatments used by agility handlers when their dog has a perceived injury keeping it from agility training and competition. Given the variety in return to sport timelines in previous studies, we also aimed to provide further description of return to sport timelines among agility dogs specific to the perceived anatomic location of the injury. Having a baseline of timeframe for return to agility following specific injuries may help guide the practitioner in developing expectations for clients as to how long the period of convalescence may be when their dog is injured.

Given the paucity of information specific to perceived injury location in the literature, the objectives of this study were to describe the type of veterinary care sought by handlers of injured agility dogs, the types of treatments the dog received, and the timeframe for return to agility training and competition.

2 Materials and methods

2.1 Study design

Data were acquired from an internet-based survey that was distributed primarily via social media during a 6-week period in 2019 (2). Individuals were eligible if they had at least one dog competing in agility in the past 3 years. Dogs were not required to have an injury for handlers to complete the survey. If handlers had more than one dog that was eligible, alphabetical order using the name of the dog was used to select the dog for which the survey was completed. The research protocol and survey were reviewed and approved by The Ohio State University Institutional Review Board.

Information about the survey has been previously published in detail (2). Briefly, handlers were asked if their dog ever had an injury that kept them from training or competing in agility for greater than 1 week. If the answer was yes, they were asked to identify all locations on the body where they believed the dog had been injured, based on a diagram illustrating and naming anatomic regions (2). Specific questions regarding each injured anatomical region were then asked. If the dog had experienced more than one injury to the same anatomical region, owners reported information for the injury that had kept the dog out of agility training and competition for the longest period of time.

Questions specific to the injury included what type(s) of care had been sought, who primarily determined treatment, the type of treatments utilized, and the length of time before the dog could return to full agility training and competition. The following options were provided regarding type of veterinary care sought: primary care, veterinary specialist, chiropractor, and other; owners were instructed to check all that applied. Similarly, owners were asked to check all that applied for options regarding treatment pursued: rest, medication, home rehabilitation, formal rehabilitation, regenerative medicine, surgery, and other. If surgery was selected, a follow up question asked owners to select the type of surgery from a pre-populated list specific to each anatomical region or write in the type of surgery if not listed. Owners were also asked who primarily determined treatment: a veterinarian, another professional (chiropractor, massage therapist, etc.), an agility trainer or friend, or the owner themself.

2.2 Statistical analysis

The percentage of owners endorsing each option for type of veterinary care sought (if any) and each treatment option was calculated for each anatomical region and 95% confidence intervals for these proportions were calculated using the Wilson score interval. As a descriptive study, no formal statistical testing was done to compare these percentages across regions. To characterize the reported length of time to return to competitive agility by anatomical region, dogs that were reported to be still undergoing treatment were excluded (as the time of the original injury was not available). Then the percentage of dogs who returned to sport within 1 month, within 3 months, within 6 months, within 1 year, and after more than a year were calculated, along with the percentage of dogs who were retired. This paper details injuries reported to be sustained to the thoracic limb (metacarpus, carpus, antebrachium, elbow and shoulder), as well as those to the pelvic limb (hip, iliopsoas, thigh, stifle, tibia, tarsus, and metatarsus). All statistical analyses were conducted using Stata v15.1.

3 Results

The sample included data from 4,197 dogs. This paper reports data on 1,714 total injuries from 1,256 unique dogs (some dogs contributed data on more than one injury).

Across all anatomical regions, owners reported seeking veterinary care for a large majority of injuries (range 80–97%,

TABLE 1 Type of veterinary care sought by owner-reported injury location.

Injury location	N[a]	Veterinary care was sought	Saw primary care veterinarian	Saw veterinary specialist	Saw chiropractor / other	Veterinarian primarily determined treatment
Thoracic Limb						
Shoulder	522	448 (86%)	266 (51%)	247 (47%)	186 (36%)	300 (57%)
Elbow	81	70 (86%)	42 (52%)	36 (44%)	20 (25%)	44/79 (56%)
Antebrachium	38	31 (82%)	25 (66%)	18 (47%)	5 (13%)	28 (74%)
Carpus	148	127 (86%)	83 (46%)	62 (34%)	29 (16%)	94/147 (64%)
Metacarpus	55	45 (82%)	36 (65%)	12 (22%)	12 (22%)	37 (67%)
Pelvic Limb						
Hip	143	116 (81%)	80 (56%)	66 (46%)	48 (34%)	76 (53%)
Iliopsoas	326	288 (88%)	147 (45%)	207 (63%)	115 (35%)	180 (55%)
Thigh	102	82 (80%)	52 (51%)	45 (44%)	22 (22%)	52 (51%)
Stifle	213	206 (97%)	118 (55%)	152 (71%)	47 (22%)	149 (70%)
Tibia	31	25 (81%)	13 (42%)	19 (61%)	5 (16%)	20 (65%)
Tarsus	34	32 (94%)	21 (62%)	18 (53%)	13 (38%)	21 (62%)
Metatarsus	21	18 (86%)	14 (67%)	7 (33%)	3 (14%)	13 (62%)

[a]With available treatment data.

Table 1; Figure 1A). Owners were most likely to seek any veterinary care (97%) and specialty veterinary care (71%) for reported stifle injuries. Owners were also likely to seek specialty veterinary care for reported iliopsoas (63%) and tibia (61%) injuries (Table 1; Figure 1B). Owners stated that a veterinarian primarily determined treatment for over 50% of injuries across all reported locations (range: 51–74%, Table 1; Figure 1C), with percentages exceeding 70% for the stifle and antebrachium (Figures 1D,E).

Reported treatments were generally similar across all injuries to the pelvic and thoracic limbs (Table 2; Figure 2). Rest was the most common treatment reported (above 85% for all except stifle, Table 2; Figure 2A), and medication use was also similar across all locations (46–60%, Table 2; Figure 2B). There was greater variation in the percentage of owners reporting both home and formal rehabilitation as a treatment based on perceived injury location. Both formal and home rehabilitation were most frequently utilized for reported iliopsoas and tarsal injuries (Table 2; Figures 2C,D). Regenerative medicine and surgery were infrequent treatments for all locations, except surgery was common (44%) for reported stifle injuries (Table 2; Figures 2E,F). Of the 94 dogs who had surgery for treatment of their reported stifle injury, owners stated that 63 (67%) had a corrective osteotomy for cranial cruciate ligament (CCL) rupture. The remainder were stated to be luxating patella correction ($n = 15$; 16%), lateral suture stabilization for CCL rupture ($n = 9$; 10%), or another surgery ($n = 7$; 7%).

Return to training and competition within 3 months was common (>67%) for most perceived injury locations (Table 3; Figure 3A). Prolonged convalescence (>6 months or retired) was noted for injuries reported to be to the iliopsoas, stifle, tibia, and tarsus, with reported stifle injuries having the longest time to return to sport (Table 3; Figure 3B). Retirement rates were low (11% or lower) for all locations except stifle (23%) and tarsus (18%) (Table 3; Figure 3C).

4 Discussion

This study describes veterinary care, treatment and outcomes following injury to the thoracic and pelvic limbs as reported by owners of agility dogs. This population of handlers sought veterinary care for 80–97% of reported injuries in their agility dogs, regardless of perceived anatomical location. These percentages are higher than previous reports from North America and Finland where veterinary care for agility dog injuries was sought 40–80% of the time (3, 4, 6). Differences may be due to variability in the wording and definitions in questions related to injuries, selection bias in the surveys, or changes in mindset of handlers regarding treatment of injuries over time. This study asked owners to report on the most serious injury to each specific location, whereas Inkila et al. (6) studied all injuries within a calendar year, and thus likely reported on a larger percentage of minor injuries as compared to this study. Perceived minor injuries may have influenced the handlers to not seek veterinary care, resulting in the lower percentage of owners seeking veterinary evaluation overall. The increased percentage of handlers seeking veterinary care in 2019, as compared to the 2009 survey by Levy et al. (4), and 2013 survey by Cullen et al. (3) could be a result of the growth of sports medicine and rehabilitation specialty care. Canine rehabilitation became increasingly popular in Europe and the United Kingdom in the 1980's, with North America closely following in the 1990's with recognition by the AVMA of the American College of Veterinary Sports Medicine and Rehabilitation in 2010 as the newest specialty in veterinary medicine (7). Thus, the development of sports medicine and rehabilitation as a specialty recognized by the American and European specialty colleges has likely increased awareness of sport related injuries among agility handlers.

In this study, handlers sought specialty veterinary care most commonly for reported stifle injuries (71%). The higher rate of specialty care pursued for reported stifle injury compared to others

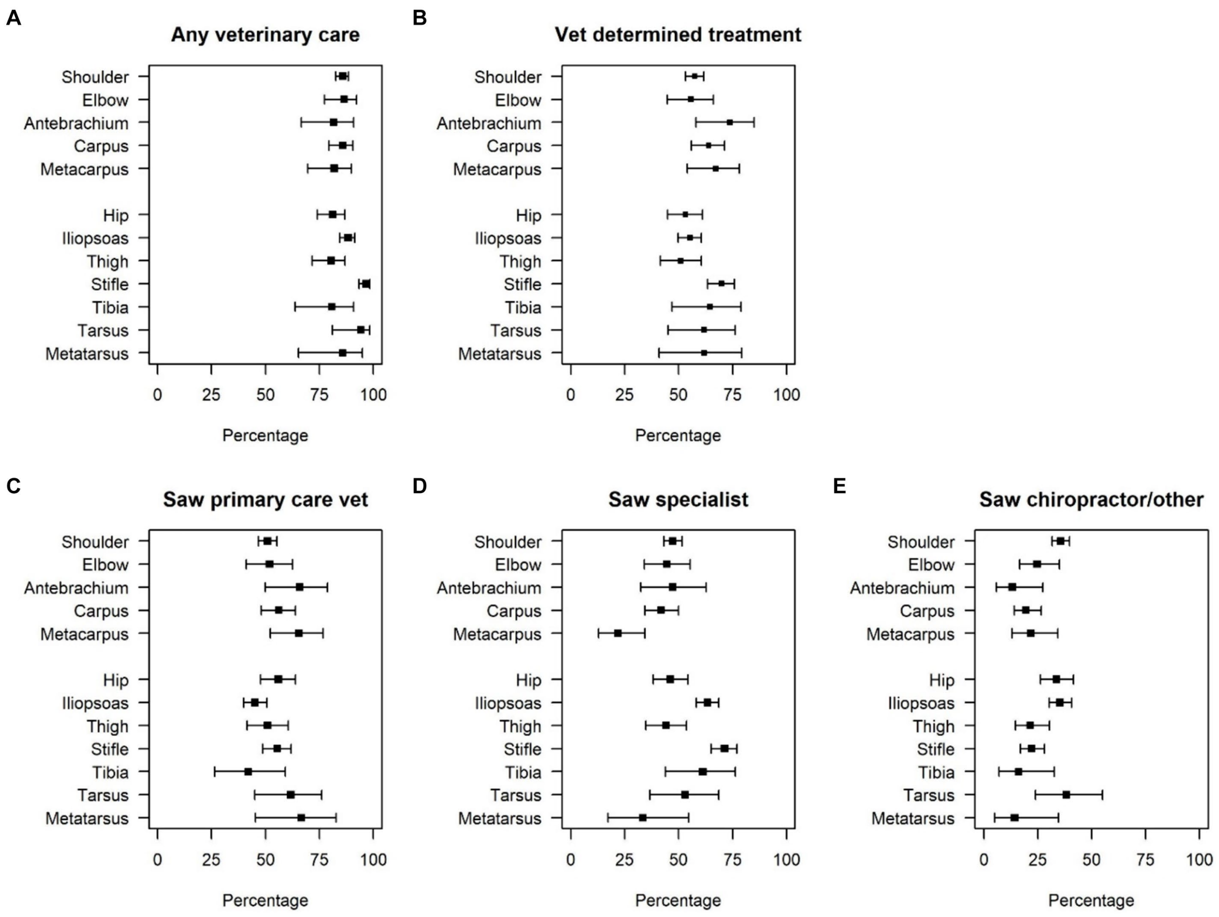

FIGURE 1
Type of veterinary care sought by owner-reported injury location. Bars indicate 95% confidence intervals for the estimated proportions. Panel **(A)** shows the percentage of dogs that sought any veterinary care, panel **(B)** shows the percentage of dogs in which a veterinarian determined treatment, panel **(C)** shows the percentage of dogs that sought primary veterinary care, panel **(D)** is the percentage of dogs that saw a veterinary specialist and panel **(E)** shows the percentage of dogs that sought care from a chiropractor/other.

TABLE 2 Types of treatment pursued by owner-reported injury location.

Injury location	Rest	Medication	Home rehabilitation	Formal rehabilitation	Regenerative medicine	Surgery
Thoracic Limb						
Shoulder	475 (91%)	242 (46%)	282 (54%)	193 (37%)	44 (8%)	31 (6%)
Elbow	71 (88%)	47 (58%)	42 (52%)	25 (31%)	3 (4%)	5 (6%)
Antebrachium	35 (92%)	24 (63%)	18 (47%)	8 (21%)	1 (3%)	4 (11%)
Carpus	138 (93%)	89 (60%)	51 (34%)	42 (28%)	8 (5%)	7 (5%)
Metacarpus	50 (91%)	33 (60%)	14 (25%)	6 (11%)	2 (4%)	4 (7%)
Pelvic Limb						
Hip	123 (86%)	75 (52%)	71 (50%)	57 (40%)	7 (5%)	8 (6%)
Iliopsoas	300 (92%)	154 (47%)	223 (68%)	184 (56%)	10 (3%)	0 (0%)
Thigh	94 (92%)	48 (47%)	56 (55%)	39 (38%)	2 (2%)	3 (3%)
Stifle	159 (75%)	107 (50%)	106 (50%)	90 (42%)	22 (10%)	94 (44%)
Tibia	27 (87%)	17 (55%)	16 (52%)	10 (32%)	1 (3%)	3 (10%)
Tarsus	29 (85%)	18 (53%)	25 (74%)	15 (44%)	5 (15%)	6 (18%)
Metatarsus	18 (86%)	12 (57%)	7 (33%)	7 (33%)	1 (5%)	2 (10%)

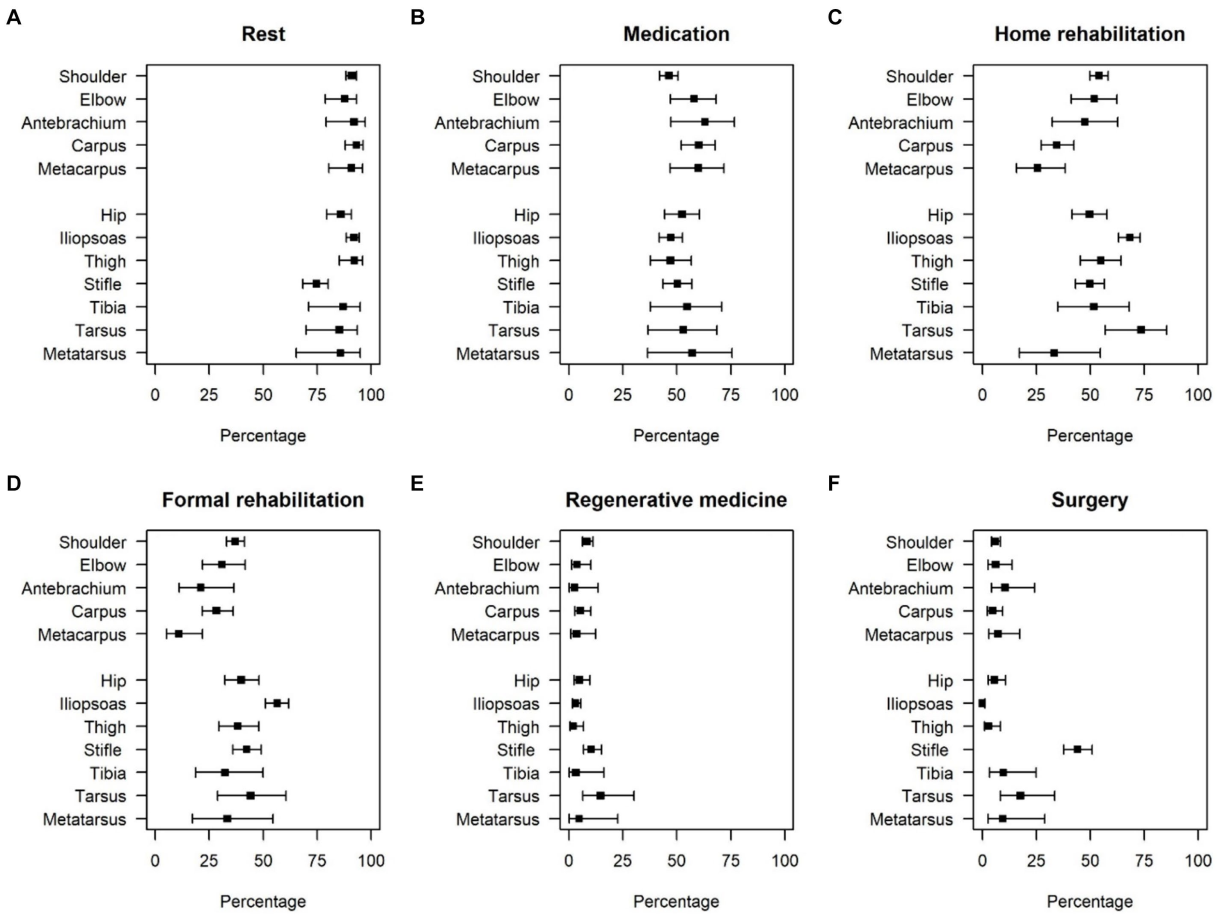

FIGURE 2
Types of treatment pursued by owner-reported injury location. Bars indicate 95% confidence intervals for the estimated proportions. Panel **(A)** shows the percentage of dogs that underwent rest, panel **(B)** shows the percentage of dogs where medication was chosen as treatment, panel **(C)** shows the percentage of dogs that underwent home rehabilitation as treatment, panel **(D)** shows the percentage of dogs that underwent formal rehabilitation as treatment, panel **(E)** shows the percentage of dogs that underwent treatment in the form of regenerative medicine, and panel **(F)** shows the percentage of dogs that underwent surgery as treatment.

TABLE 3 Time to return to competition by owner-reported injury location.

Injury location	N[a]	<1 month	1–3 months	4–6 months	6–12 months	>1 year	Retired
Thoracic Limb							
Shoulder	485	165 (34%)	164 (34%)	62 (13%)	47 (10%)	20 (4%)	27 (6%)
Elbow	77	27 (35%)	31 (40%)	6 (8%)	4 (5%)	2 (3%)	7 (9%)
Antebrachium	36	17 (47%)	8 (22%)	8 (22%)	1 (3%)	1 (3%)	1 (3%)
Carpus	136	63 (46%)	39 (29%)	16 (12%)	3 (2%)	2 (1%)	13 (10%)
Metacarpus	53	30 (57%)	13 (25%)	2 (4%)	1 (2%)	2 (4%)	5 (9%)
Pelvic Limb							
Hip	136	50 (37%)	43 (32%)	16 (12%)	9 (7%)	3 (2%)	15 (11%)
Iliopsoas	301	51 (17%)	118 (39%)	71 (24%)	32 (11%)	11 (4%)	18 (6%)
Thigh	96	35 (36%)	42 (44%)	10 (10%)	5 (5%)	(0%)	4 (4%)
Stifle	194	24 (12%)	35 (18%)	37 (19%)	32 (16%)	21 (11%)	45 (23%)
Tibia	26	6 (23%)	7 (27%)	6 (23%)	4 (15%)	2 (8%)	1 (4%)
Tarsus	33	4 (12%)	13 (39%)	3 (9%)	3 (9%)	4 (12%)	6 (18%)
Metatarsus	19	11 (58%)	5 (26%)	2 (11%)	1 (5%)	0 (0%)	0 (0%)

[a]With treatment resolved (those who reported that treatment was ongoing are excluded).

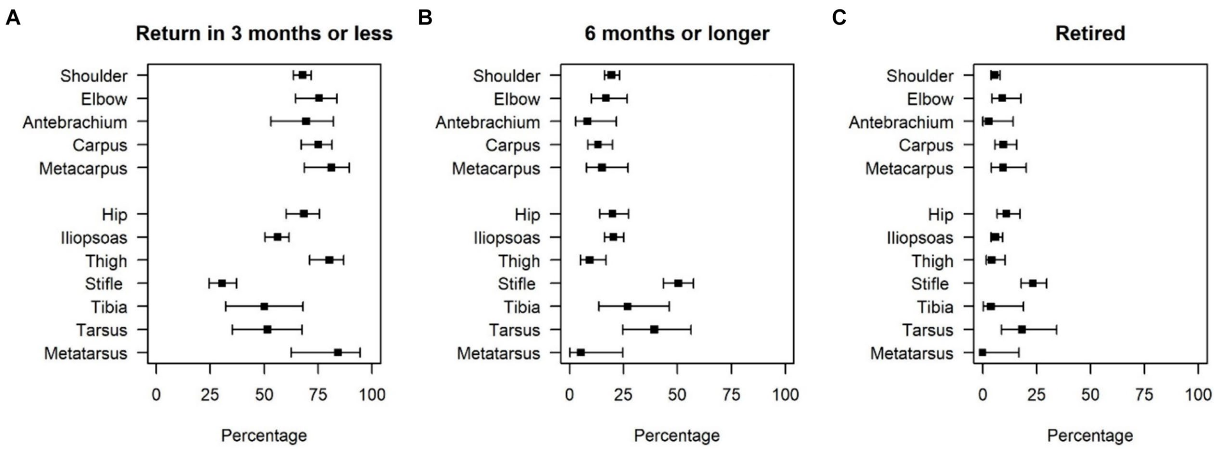

FIGURE 3
Percentage of dogs returning to training and competition by owner-reported injury location within different time frames. **(A)** Shows the percentage of dogs returning within 3 months, **(B)** shows the percentage of dogs who took more than 6 months or were retired, and **(C)** shows the percentage of dogs who were retired.

may be due to the nature of stifle injury. The most reported stifle injury was cranial cruciate ligament (CCL) injury, for which advanced surgical intervention is often the treatment of choice, as surgical treatment results in better outcomes than conservative management, with corrective osteotomies reported to have a better outcome than other surgical procedures such as extracapsular stabilization (8–11). Given the advanced skills necessary to perform an osteotomy stabilization, many of these cases are referred to specialists for care. In contrast, reported distal limb injuries were least frequently seen by a specialist, with only 22% of metacarpal injuries and 33% of metatarsal injuries seen by a specialist. This may be due to the comfort level of primary care veterinarians in treating distal extremity injuries, as many only require rest and do not often require advanced diagnostics or treatment.

Reported iliopsoas injuries were also seen frequently by veterinary specialists (63%). Definitive diagnosis of this injury requires advanced imaging such as musculoskeletal ultrasound or magnetic resonance imaging (MRI), which are most commonly available in specialty practices. It is also often a diagnosis of exclusion of underlying pathology. Evaluation can be time consuming and challenging, and as such these cases are often referred (12–15). Iliopsoas injuries are most commonly treated with rest in combination with formal rehabilitation and are rarely treated surgically (16). Therefore, it is not unexpected that our study showed that rest was the most common treatment, followed by home rehabilitation and formal rehabilitation.

Interestingly, only 47% of dogs with reported shoulder injuries were seen by a veterinary specialist. The most reported specific shoulder injuries were biceps tendinopathy, supraspinatus tendinopathy, and medial shoulder instability, all of which also require advanced imaging, such as musculoskeletal ultrasound, MRI, or arthroscopy for definitive diagnosis (2, 17–20). It is unknown why fewer handlers of dogs with shoulder injuries seek specialty veterinary care compared to other complex soft tissue injuries like iliopsoas injuries given their complexity in obtaining a definitive diagnosis and treatment required for return to sport.

Conservative treatment options in this survey included rest, medication, home rehabilitation, and formal rehabilitation. Rest was the most reported treatment among all reported locations of injury. Medication was also a prevalent treatment for all injury locations, with reported use in 46–60% of cases. This may be due to the fact that most injuries sustained by agility dogs are soft tissue injuries that historically have been treated with rest and medications (4, 21). Among the thoracic limb injuries, home and formal rehabilitation was most often pursued for reported shoulder injuries. As noted earlier, the most commonly reported injury to the shoulder was biceps tendinopathy representing about 19% of shoulder injuries in agility dogs (2). Treatments reported to result in improvement in biceps tendinopathy include extracorporeal shockwave therapy and rehabilitation therapy exercises, so the higher rates of rehabilitation therapy in shoulder injuries is not surprising (18, 22). For pelvic limb injuries, home and formal rehabilitation were most frequently sought by handlers for reported iliopsoas injuries. While there is minimal research evaluating response of iliopsoas injuries to rehabilitation therapy, it is generally accepted that rest and rehabilitation therapy are the treatments of choice (14, 16, 23).

Regenerative medicine was most often pursued for injuries reported to be to the shoulder (8%), stifle (10%) and tarsus (15%), but overall use was low. Orthobiologics, such as platelet rich plasma (PRP), are frequently utilized in human athletic injuries, such as hamstring, anterior cruciate ligament (ACL), and ankle injuries, and have shown shorter return to play rates as compared to those athletes that did not receive platelet rich plasma as a part of their treatment plan (24–27). Based on this survey, the use of regenerative therapies is not yet a mainstay of therapy in canine agility injuries. Initial retrospective studies have reported improvement in shoulder and stifle injuries with orthobiologics, however prospective data is lacking (28–30). If prospective studies demonstrate improved outcomes and return to sport after injury in canine athletes, it is likely that regenerative medicine will become a more common treatment modality.

The ability and the time needed to return to sport is often of utmost concern to the agility handler. In this study, reported return to agility training and competition rates were high (89% or above) across all anatomic regions except stifle (77%) and tarsus (82%). The only previous report described an overall rate of return to agility after injury of 67%, with a decreased rate of return to agility competition in surgically treated dogs (61%) as compared to conservatively treated dogs (70%), among all injuries (31). The higher return to sport rates in our study may reflect increased access to specialty care and improved treatment options, but may also reflect differences between the samples due to differences in recruitment and injury definition. What was not ascertained via this survey is the number of owners who returned to sport with clearance from a veterinarian. Owners may have elected to return to sport sooner than recommended, or without veterinary oversight at all.

The high rate of retirement among reported stifle injuries was not surprising, as previous studies have noted a very high rate of retirement (35–48%) following surgical correction of CCL injury (31, 32). Among the 72 dogs in our sample who underwent any surgical correction of CCL injury, 22 (31%) did not return to training or competition, with the retirement rate among the dogs who underwent osteotomy qualitatively lower (18/63; 29%) than those who underwent lateral suture stabilization (4/9; 44%). Previous studies regarding outcomes after surgical treatment of CCL rupture in the general canine population show that patients who undergo a tibial plateau leveling osteotomy (TPLO) have an excellent return to function and secondary high owner satisfaction (8, 33, 34). However, outcome and return to agility competition-level function following surgical treatment of the stifle is much lower than the reported success rates in the general dog population. When comparing ACL tears in elite human athletes, a recent meta-analysis estimated the return to sport at a similar sports performance level is 83% (35), which is higher than we observed for canine athletes with CCL tears. This is likely due to the differences in pathophysiology of cruciate ligament disease between humans and canines. Cruciate disease in dogs is typically degenerative in nature, with a smaller percentage of cases being traumatic, whereas ACL tears in humans are predominantly traumatic in origin (36). Given the differences in pathophysiology, canine ligamentous repair has not proven successful and stabilization using osteotomy-based procedures like TPLO are the standard of care, whereas standard of care in humans is primary ligamentous repair followed by extensive physical therapy (37, 38). Due to the differences in pathophysiology and repair between human and canines, it is possible that canine athletes have more chronic and degenerative changes and secondary osteoarthritis compared to their human counterparts, thereby resulting in more challenges with returning to competition-level sport. However, this is difficult to infer as the prevalence of osteoarthritis in this patient population is not known. Furthermore, the rate of meniscal injury concurrently seen with cruciate injury in dogs is significantly higher than that of humans (39). This could also impact ability to return to high level sport post-injury. The percentage of dogs receiving post-operative rehabilitation therapy is also likely significantly lower than in humans, which could also contribute to the lower rates of returning to sport-level functionality. Although rehabilitation therapy has been noted to benefit patient outcome post TPLO by increasing muscle mass and stifle range of motion, it is not currently standard of care and the frequency of post-operative rehabilitation therapy is unknown in the canine population (36, 40–44).

The high rate of retirement following reported tarsal injury was unexpected. When evaluating this survey population, most of the reported tarsal surgical procedures were due to fracture (2). Racing greyhound athletes have a high rate of tarsal injuries and fractures that typically require retirement from the sport, with greater than 29% of dogs retiring following surgery (45). The higher rate of retirement and reduced ability to return to sport after tarsal injury is likely due to the complex nature of the tarsal joint and sequelae associated with injury such as degenerative joint disease, which is typically not well tolerated in the tarsal joint, particularly in highly competitive athletic dogs (45).

In contrast to the stifle and tarsus, handlers in this study reported a 94% return to sport among dogs after a reported shoulder injury, which is similar to previous studies (30). No prospective studies have assessed what type of treatment is ideal for shoulder injuries, with treatments ranging from formal rehabilitation therapy alone, to a variety of regenerative medicine treatments, and surgical intervention (29, 30, 46, 47). Shoulder injuries in human athletes in sports such as baseball have low rates of return to play and return to prior performance. One study compared surgical and non-surgical treatments for baseball pitches and reported similar return to play rates (39 and 40%, respectively) and slightly higher return to prior performance in those treated non-surgically (7% vs. 22%) (48). Return to prior performance rates in human baseball athletes compared to dogs is likely substantially different due to distinct differences in the functionality of the shoulder joint between the two species. The shoulder joint in dogs has an important function in weight bearing unlike the shoulder joint in humans (49). Additionally, the human shoulder joint has significantly increased mobility when compared to the canine shoulder joint, which is limited due to muscular and tendinous attachments medially limiting range of motion (49). Although further prospective studies are needed to evaluate return to agility for canine patients with shoulder injuries, there has been noted improvement in return to sport using orthobiologics and rehabilitation therapy following shoulder injuries (29, 46).

An important factor when considering rate of retirement for any injury is that handlers are responsible for deciding if and when their dog returns to agility training and competition following injury. They are also responsible for deciding whether training or competition variables, such as level, organization, and jump height are adjusted. Ultimately, they are also responsible for when the dog is returned to training and sport following injury. This study did not ask about performance prior to or after injury treatment, nor did the survey ask the specific reason for retirement. Thus, it is a limitation of this study that handlers may have decided to retire injured dogs due to variables unrelated to the physical inability to continue to participate as a sequela to the injury or treatment outcome.

Other limitations of this study include potential inaccuracies related to participant recall and the reporting of injuries that were not diagnosed or confirmed by a veterinarian. However, as one of the primary aims of this study was to characterize the percentage of times handlers were seeking veterinary care for perceived injuries, self-report is the only option. It is possible, however, that there was differential misclassification of the injured region, with handlers perceiving the locations of injuries to some anatomic locations better than others. Even among injuries seen by veterinary professionals, specific treatment information and definitive diagnoses were not available due to a lack of access to veterinary records. Given the nature of the available data, we did not assess potential associations between treatments and return to sport outcomes. Return to sport is dependent on the severity of injury, regardless of treatment, and our study had no information on the severity of the initial injury. Therefore, it is highly likely that severity would significantly confound the association between treatments received and return to sport, and thus these associations were not assessed in this study. Prospectively collected data with details on injury severity, are needed to assess the impact of treatments on return to sport outcome. Future studies should also assess reinjury rate, and how this differs based on treatment. Selection bias in a convenience sample survey is inherent and therefore this sample may not perfectly reflect the overall agility population. Despite the limitations of this study, the data reported provide valuable insight into how handlers of agility dogs seek care, how injuries in agility dogs are treated, and the variation in return to sport times among these dogs. These data can help inform prognosis for return to sport, though they should be used cautiously. The low return to sport after stifle and tarsal injury suggests that additional studies are needed regarding these injuries, aiding in improvement of treatment strategies. Additionally, this survey indicates the need for future prospective studies evaluating expected return to agility for specific injuries and how treatment approaches affect sport-specific outcomes.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the animal study because the Ohio State University Office of Responsible Research Practices determined the project was exempt from IRB review as it was an owner-based internet survey and the information was recorded without direct or indirect identifiers. The patients/participants provided their written informed consent to participate in this study.

Author contributions

BA: Writing – original draft, Writing – review & editing. AP: Conceptualization, Data curation, Investigation, Methodology, Writing – review & editing. AS: Data curation, Formal analysis, Investigation, Methodology, Software, Writing – review & editing. NK: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. DeYoung C. Director of agility American Kennel Club (2020).

2. Pechette Markley A, Shoben AB, Kieves NR. Internet-based survey of the frequency and types of orthopedic conditions and injuries experienced by dogs competing in agility. *J Am Vet Med Assoc*. (2021) 259:1001–8. doi: 10.2460/javma.259.9.1001

3. Cullen KL, Dickey JP, Bent LR, Thomason JJ, Moëns NMM. Internet-based survey of the nature and perceived causes of injury to dogs participating in agility training and competition events. *J Am Vet Med Assoc*. (2013) 243:1010–8. doi: 10.2460/javma.243.7.1010

4. Levy M, Hall C, Trentacosta N, Percival M. A preliminary retrospective survey of injuries occurring in dogs participating in canine agility. *Vet Comp Orthop Traumatol*. (2009) 22:321–4. doi: 10.3415/VCOT-08-09-0089

5. Evanow JA, VanDeventer G, Dinallo G, Mann S, Frye CW, Wakshlag JJ. Internet survey of participant demographics and risk factors for injury in competitive agility dogs. *VCOT Open*. (2021) 4:e92–8. doi: 10.1055/s-0041-1735843

6. Inkilä L, Hyytiäinen HK, Hielm-Björkman A, Junnila J, Bergh A, Boström A. Part II of Finnish agility dog survey: agility-related injuries and risk factors for injury in competition-level agility dogs. *Animals (Basel)*. (2022) 12:12. doi: 10.3390/ani12030227

7. Sports medicine and rehab specialty recognized | American Veterinary Medical Association (2010). Available at: https://www.avma.org/javma-news/2010-06-01/sports-medicine-and-rehab-specialty-recognized (Accessed March 28, 2024).

8. Nelson SA, Krotscheck U, Rawlinson J, Todhunter RJ, Zhang Z, Mohammed H. Long-term functional outcome of tibial plateau leveling osteotomy versus extracapsular repair in a heterogeneous population of dogs. *Vet Surg*. (2013) 42:38–50. doi: 10.1111/j.1532-950X.2012.01052.x

9. Krotscheck U, Nelson SA, Todhunter RJ, Stone M, Zhang Z. Long term functional outcome of tibial tuberosity advancement vs. tibial plateau leveling osteotomy and extracapsular repair in a heterogeneous population of dogs. *Vet Surg*. (2016) 45:261–8. doi: 10.1111/vsu.12445

10. Gordon-Evans WJ, Griffon DJ, Bubb C, Knap KM, Sullivan M, Evans RB. Comparison of lateral fabellar suture and tibial plateau leveling osteotomy techniques for treatment of dogs with cranial cruciate ligament disease. *J Am Vet Med Assoc*. (2013) 243:675–80. doi: 10.2460/javma.243.5.675

11. Pegram C, Diaz-Ordaz K, Brodbelt DC, Chang Y-M, von Hekkel AF, Wu C-H, et al. Target trial emulation: does surgical versus non-surgical management of cranial cruciate ligament rupture in dogs cause different outcomes? *Prev Vet Med*. (2024) 226:106165. doi: 10.1016/j.prevetmed.2024.106165

12. Fry LM, Kieves NR, Shoben AB, Rychel JK, Pechette MA. Internet survey evaluation of iliopsoas injury in dogs participating in agility competitions. *Front Vet Sci*. (2022) 9:930450. doi: 10.3389/fvets.2022.930450

13. Sack D, Canapp D, Canapp S, Majeski S, Curry J, Sutton A, et al. Iliopsoas strain demographics, concurrent injuries, and grade determined by musculoskeletal ultrasound in 72 agility dogs. *Can J Vet Res*. (2023) 87:196–201.

14. Cabon Q, Bolliger C. Iliopsoas muscle injury in dogs. *Compend Contin Educ Vet*. (2013) 35:E2.

15. Cullen R, Canapp D, Dycus D, Carr B, Ibrahim V, Canapp S. Clinical evaluation of iliopsoas strain with findings from diagnostic musculoskeletal ultrasound in agility performance canines – 73 cases. *Vet Evid*. (2017) 2:2. doi: 10.18849/ve.v2i2.93

16. Spinella G, Davoli B, Musella V, Dragone L. Observational study on lameness recovery in 10 dogs affected by iliopsoas injury and submitted to a physiotherapeutic approach. *Animals (Basel)*. (2021) 11:11. doi: 10.3390/ani11020419

17. Kramer M, Gerwing M, Sheppard C, Schimke E. Ultrasonography for the diagnosis of diseases of the tendon and tendon sheath of the biceps brachii muscle. *Vet Surg*. (2001) 30:64–71. doi: 10.1053/jvet.2001.20336

18. Kern T, Manfredi J, Tomlinson J. Ultrasonographic appearance of supraspinatus and biceps tendinopathy improves in dogs treated with low-intensity extracorporeal shock wave therapy: a retrospective study. *Front Vet Sci*. (2023) 10:1238513. doi: 10.3389/fvets.2023.1238513

19. Murphy SE, Ballegeer EA, Forrest LJ, Schaefer SL. Magnetic resonance imaging findings in dogs with confirmed shoulder pathology. *Vet Surg*. (2008) 37:631–8. doi: 10.1111/j.1532-950X.2008.00429.x

20. Lassaigne CC, Boyer C, Sautier L, Taeymans O. Ultrasound of the normal canine supraspinatus tendon: comparison with gross anatomy and histology. *Vet Rec*. (2020) 186:e14. doi: 10.1136/vr.105552

21. Cullen KL, Dickey JP, Bent LR, Thomason JJ, Moëns NMM. Survey-based analysis of risk factors for injury among dogs participating in agility training and competition events. *J Am Vet Med Assoc*. (2013) 243:1019–24. doi: 10.2460/javma.243.7.1019

22. Leeman JJ, Shaw KK, Mison MB, Perry JA, Carr A, Shultz R. Extracorporeal shockwave therapy and therapeutic exercise for supraspinatus and biceps tendinopathies in 29 dogs. *Vet Rec*. (2016) 179:385. doi: 10.1136/vr.103487

23. Henderson AL, Latimer C, Millis DL. Rehabilitation and physical therapy for selected orthopedic conditions in veterinary patients. *Vet Clin North Am Small Anim Pract*. (2015) 45:91–121. doi: 10.1016/j.cvsm.2014.09.006

24. Fitzpatrick J, Bulsara M, Zheng MH. The effectiveness of platelet-rich plasma in the treatment of tendinopathy: a meta-analysis of randomized controlled clinical trials. *Am J Sports Med*. (2017) 45:226–33. doi: 10.1177/0363546516643716

25. Kantrowitz DE, Padaki AS, Ahmad CS, Lynch TS. Defining platelet-rich plasma usage by team physicians in elite athletes. *Orthop J Sports Med*. (2018) 6:232596711876707. doi: 10.1177/2325967118767077

26. Hada S, Hada M, Yoshida K, Kaneko H, Saita Y, Kubota M, et al. Conservative treatment using platelet-rich plasma for acute anterior cruciate ligament injuries in highly active patients: a retrospective survey. *Cureus*. (2024) 16:e53102. doi: 10.7759/cureus.53102

27. Laver L, Carmont MR, McConkey MO, Palmanovich E, Yaacobi E, Mann G, et al. Plasma rich in growth factors (PRGF) as a treatment for high ankle sprain in elite athletes: a randomized control trial. *Knee Surg Sports Traumatol Arthrosc*. (2015) 23:3383–92. doi: 10.1007/s00167-014-3119-x

28. Canapp SO, Leasure CS, Cox C, Ibrahim V, Carr BJ. Partial cranial cruciate ligament tears treated with stem cell and platelet-rich plasma combination therapy in 36 dogs: a retrospective study. *Front Vet Sci*. (2016) 3:112. doi: 10.3389/fvets.2016.00112

29. McDougall RA, Canapp SO, Canapp DA. Ultrasonographic findings in 41 dogs treated with bone marrow aspirate concentrate and platelet-rich plasma for a supraspinatus tendinopathy: a retrospective study. *Front Vet Sci*. (2018) 5:98. doi: 10.3389/fvets.2018.00098

30. Canapp SO, Canapp DA, Ibrahim V, Carr BJ, Cox C, Barrett JG. The use of adipose-derived progenitor cells and platelet-rich plasma combination for the treatment of supraspinatus tendinopathy in 55 dogs: a retrospective study. *Front Vet Sci*. (2016) 3:61. doi: 10.3389/fvets.2016.00061

31. Tomlinson JE, Manfredi JM. Return to sport after injury: a web-based survey of owners and handlers of agility dogs. *Vet Comp Orthop Traumatol*. (2018) 31:473–8. doi: 10.1055/s-0038-1670676

32. Heidorn SN, Canapp SO, Zink CM, Leasure CS, Carr BJ. Rate of return to agility competition for dogs with cranial cruciate ligament tears treated with tibial plateau leveling osteotomy. *J Am Vet Med Assoc*. (2018) 253:1439–44. doi: 10.2460/javma.253.11.1439

33. Christopher SA, Beetem J, Cook JL. Comparison of long-term outcomes associated with three surgical techniques for treatment of cranial cruciate ligament disease in dogs. *Vet Surg*. (2013) 42:329–34. doi: 10.1111/j.1532-950X.2013.12001.x

34. Nanda A, Hans EC. Tibial plateau leveling osteotomy for cranial cruciate ligament rupture in canines: patient selection and reported outcomes. *Vet Med (Auckl)*. (2019) 10:249–55. doi: 10.2147/VMRR.S204321

35. Lai CCH, Ardern CL, Feller JA, Webster KE. Eighty-three per cent of elite athletes return to preinjury sport after anterior cruciate ligament reconstruction: a systematic review with meta-analysis of return to sport rates, graft rupture rates and performance outcomes. *Br J Sports Med*. (2018) 52:128–38. doi: 10.1136/bjsports-2016-096836

36. Griffon DJ. A review of the pathogenesis of canine cranial cruciate ligament disease as a basis for future preventive strategies. *Vet Surg*. (2010) 39:399–409. doi: 10.1111/j.1532-950X.2010.00654.x

37. Dragicevic-Cvjetkovic D, Jandric S, Bijeljac S, Palija S, Manojlovic S, Talic G. The effects of rehabilitation protocol on functional recovery after anterior cruciate ligament reconstruction. *Med Arch*. (2014) 68:350–2. doi: 10.5455/medarh.2014.68.350-352

38. Badawy CR, Jan K, Beck EC, Fleet N, Taylor J, Ford K, et al. Contemporary principles for postoperative rehabilitation and return to sport for athletes undergoing anterior cruciate ligament reconstruction. *Arthrosc Sports Med Rehabil*. (2022) 4:e103–13. doi: 10.1016/j.asmr.2021.11.002

39. Binversie EE, Walczak BE, Cone SG, Baker LA, Scerpella TA, Muir P. Canine ACL rupture: a spontaneous large animal model of human ACL rupture. *BMC Musculoskelet Disord*. (2022) 23:116. doi: 10.1186/s12891-021-04986-z

40. Alvarez LX, Repac JA, Kirkby Shaw K, Compton N. Systematic review of postoperative rehabilitation interventions after cranial cruciate ligament surgery in dogs. *Vet Surg*. (2022) 51:233–43. doi: 10.1111/vsu.13755

41. Monk ML, Preston CA, McGowan CM. Effects of early intensive postoperative physiotherapy on limb function after tibial plateau leveling osteotomy in dogs with deficiency of the cranial cruciate ligament. *Am J Vet Res*. (2006) 67:529–36. doi: 10.2460/ajvr.67.3.529

42. Baltzer WI, Smith-Ostrin S, Warnock JJ, Ruaux CG. Evaluation of the clinical effects of diet and physical rehabilitation in dogs following tibial plateau leveling osteotomy. *J Am Vet Med Assoc*. (2018) 252:686–700. doi: 10.2460/javma.252.6.686

43. Kirkby Shaw K, Alvarez L, Foster SA, Tomlinson JE, Shaw AJ, Pozzi A. Fundamental principles of rehabilitation and musculoskeletal tissue healing. *Vet Surg*. (2020) 49:22–32. doi: 10.1111/vsu.13270

44. Eiermann J, Kirkby-Shaw K, Evans RB, Knell SC, Kowaleski MP, Schmierer PA, et al. Recommendations for rehabilitation after surgical treatment of cranial cruciate ligament disease in dogs: a 2017 survey of veterinary practitioners. *Vet Surg*. (2020) 49:80–7. doi: 10.1111/vsu.13294

45. Guilliard MJ. The nature, incidence and response to treatment of injuries to the distal limbs in the racing greyhound. Doctoral dissertation. (2012).

46. Entani MG, Franini A, Dragone L, Barella G, De Rensis F, Spattini G. Efficacy of serial Ultrasonographic Examinations in Predicting Return to play in agility dogs with shoulder lameness. *Animals (Basel)*. (2021) 12:12. doi: 10.3390/ani12010078

47. Kieves NR, Jones S. There is no superior treatment method for medial shoulder instability in dogs. *Vet Evid*. (2020) 5. doi: 10.18849/ve.v5i1.249

48. Fedoriw WW, Ramkumar P, McCulloch PC, Lintner DM. Return to play after treatment of superior labral tears in professional baseball players. *Am J Sports Med*. (2014) 42:1155–60. doi: 10.1177/0363546514528096

49. Sager M, Herten M, Ruchay S, Assheuer J, Kramer M, Jäger M. The anatomy of the glenoid labrum: a comparison between human and dog. *Comp Med*. (2009) 59:465–75.

TYPE Original Research
PUBLISHED 25 September 2024
DOI 10.3389/fvets.2024.1449343

OPEN ACCESS

EDITED BY
Denis J. Marcellin-Little,
University of California, Davis, United States

REVIEWED BY
Joseph Wakshlag,
Cornell University, United States
Matthew Warren Brunke,
Veterinary Referral Associates, United States
Janice L. Huntingford,
Essex Animal Hospital, Canada

*CORRESPONDENCE
Lindsay Hochman Elam
✉ Lindsay.Elam@colostate.edu

RECEIVED 14 June 2024
ACCEPTED 22 August 2024
PUBLISHED 25 September 2024

CITATION
Talsma B, Elam LH, McGrath S, Zhou T, Webb CB and Duerr FM (2024) Evaluation of the effect of cannabidiol administration with and without nonsteroidal anti-inflammatory drugs in dogs with mobility disorders: a prospective, double-blind, crossover, placebo-controlled study.
Front. Vet. Sci. 11:1449343.
doi: 10.3389/fvets.2024.1449343

Evaluation of the effect of cannabidiol administration with and without nonsteroidal anti-inflammatory drugs in dogs with mobility disorders: a prospective, double-blind, crossover, placebo-controlled study

Bryce Talsma[1], Lindsay Hochman Elam[1]*, Stephanie McGrath[1], Tianjian Zhou[2], Craig B. Webb[1] and Felix Michael Duerr[1]

[1]Department of Clinical Sciences, Colorado State University, Fort Collins, CO, United States,
[2]Department of Statistics, Colorado State University, Fort Collins, CO, United States

Introduction: With rapidly growing interest in the use of cannabidiol (CBD) in the management of pain and other conditions, more information is needed on the safety and efficacy of this supplement, particularly its co-administration with commonly used pharmaceuticals such as non-steroidal anti-inflammatory drugs (NSAIDs). This study sought to assess the effect of CBD in dogs with mobility impairments, as well as evaluate the clinical tolerance of CBD used together with NSAIDs.

Materials and methods: Forty-two client-owned dogs with diagnosed mobility impairments were enrolled in this prospective, double-blind, crossover, placebo-controlled study. Baseline data were collected for 10–14 days followed by random allocation to either placebo or CBD oil for 45 days with a 30-day washout period in between. CBD was dosed at 5 mg/kg orally every 12 h with masked placebo administered at equal volume. Outcome measures included objective gait analysis, accelerometry, and clinical metrology instruments. CBD plasma levels and serum biochemistry were also collected along with hepatic ultrasound if warranted.

Results: Thirty-eight dogs finished the study with thirty-nine included for at least partial analysis. Compared to baseline, dogs receiving CBD showed evidence of improved outcomes based on blinded veterinary assessments and accelerometer data. Compared to placebo, dogs receiving CBD showed some evidence of improved outcomes on CBPI, CSOM, and blinded veterinary assessments, but not for objective outcome measures. There was evidence of increased ALP when CBD was co-administered with NSAIDs compared to CBD administration alone. Additionally, there was evidence of ALT elevations with CBD and NSAID co-administration, but this elevation did not show evidence of an increase over CBD use alone.

Discussion: These results suggest a potential therapeutic benefit in the administration of CBD for the management of mobility impairments, but greater

ALP elevations were seen when administered with NSAIDs. While the sample size of dogs that received further hepatic work-up for liver enzyme elevations is small, chosen diagnostics varied, and liver biopsies were not performed, there did not appear to be clinically apparent liver damage. Further research is needed to better understand the efficacy of CBD in a larger population of dogs and patient tolerance and safety when administered with NSAIDs or other medications long term.

KEYWORDS

cannabidiol, CBD, dog, mobility, NSAID, osteoarthritis

1 Introduction

Mobility is a key component to perceived quality of life in both human and veterinary patients (1). In canines, a large population study reported musculoskeletal disease and the inability to stand as the leading cause of euthanasia in German Shepherd dogs, surpassing neoplasia (2). Mobility impairments are commonly treated with a multimodal approach to manage a patient's clinical signs with nonsteroidal anti-inflammatory drugs (NSAIDs) currently considered the first-line standard of care. Despite a systematic review indicating low instances of severe adverse events related to NSAID administration (3), there is concern for its long-term use in patients among both veterinarians and owners (4). Monoclonal antibody medication targeted for osteoarthritis (OA) pain appears to offer another promising option for patients, but current research has not evaluated its administration long-term or in combination with NSAIDs (40). Other currently available pain medications, while generally well tolerated, appear less effective in the management of pain (5, 6). This underlines the necessity for alternative analgesic agents that are safe, efficacious, and easy to administer.

The therapeutic use of cannabinoids is of recent interest to both human and veterinary medicine (7, 8). While literature supporting its use remains limited (9), the recent declassification of industrial hemp has improved access for research in veterinary medicine. Current evidence suggests that the use of cannabidiol in dogs for the management of OA is promising, but further investigation is needed to determine the efficacy, dose, formulation, and safety of combinations with other medications (10–12). Most available studies lack the use of objective data, such as kinetic analysis and accelerometry, to evaluate efficacy. To the authors' knowledge, only one study has evaluated the efficacy of cannabidiol and NSAIDs together in dogs affected with OA using objective outcome measures (13). Given that NSAIDs remain the mainstay of therapeutic management of OA, it is desirable to find additional therapies that are both safe and effective with co-administration.

This prospective, double-blind, crossover, placebo-controlled study sought to assess the effect of CBD in dogs with mobility impairments, as well as evaluate the clinical tolerance of CBD used together with NSAIDs.

2 Materials and methods

The study protocol was approved by the Clinical Review Board of Colorado State University (IACUC: #1608, initial approval 4/1/2021), and owner consent was obtained prior to enrollment. Client-owned dogs of any breed or sex presenting to Colorado State University Veterinary Teaching Hospital with lameness or mobility impairments that resulted in measurable pain were eligible for participation. Included dogs must have been ≥10 kg, be in general good health (defined as being able to perform everyday activities such as independent eating/drinking, walking, and independently rising and laying down), not be on an active weight loss plan, adapted to wearing a collar at all times, and have a Canine Brief Pain Inventory (CBPI) average pain severity score (PSS) and pain interference score (PIS) ≥ 2 for each. If the dog had a change in the average PSS and/or PIS between baseline visits 10–14 days apart, disease was considered not stable at the time, and the dog was excluded from the study or re-evaluated when disease was considered to plateau. It was also required that the dogs were on a consistent management plan for at least 4 weeks prior to enrollment. This could include NSAIDs and other medications and supplements if they were administered consistently prior to enrollment and continued throughout the study. Dogs receiving grapiprant were excluded from enrollment, as the study sought to look at the effect of traditional NSAIDs in combination with CBD. Other exclusion criteria included disease expected to substantially change throughout the study period (i.e., neoplasia, partial rupture of the cranial cruciate ligament, degenerative myelopathy, etc.), surgery or joint injections within 3 months of enrollment, or administration of corticosteroids within the last month. Only dogs with chronic, stable stifles with osteoarthritis were enrolled to reduce the possibility of clinical worsening due to progressive tearing of the CCL or development of a meniscal tear. Dog with evidence of pre-existing liver or kidney disease (any elevation of ALT, AST, GGT, T-bilirubin, bile acids, or BUN/creatinine, respectively) were also excluded. Mild elevations in ALP, defined as 2-6x above the high end of the reference range, were included given the low specificity (51%) of ALP as a marker for hepatobiliary disease (14).

At the time of enrollment, each participant received a complete orthopedic examination, objective gait analysis, baseline bloodwork profile (complete blood count and serum biochemistry), measurement of fasted bile acids, and baseline plasma CBD value. Dogs were required to have their mobility impairment diagnosed via an objective imaging modality that supported clinical exam findings prior to trial enrollment. Additional diagnostics including radiographs, musculoskeletal ultrasound, and/or neurologic exam by a board-certified veterinary neurologist (SM) were performed at the evaluating clinician's discretion based on the patient's prior diagnostics and clinical examination. While many dogs were diagnosed with bilateral disease (e.g., elbow osteoarthritis), the most clinically affected joint was used for enrollment and evaluation of outcome measures. The owners were informed that the use of new medications, supplements, dose changes, or new treatment strategies should be avoided throughout the trial, would need to be reported, and may result in exclusion from the study if it was considered to substantially impact the patient's mobility. Minor deviations from the protocol such as a single rescue dose of an NSAID or new medications for a condition not affecting mobility (e.g., antibiotics) were deemed acceptable.

2.1 Treatment groups

Dogs were categorized as either receiving NSAID therapy or not receiving NSAID therapy during enrollment to ensure each group had the same number of dogs. Participants were allocated into one of two treatment groups using the random generator function in Microsoft Excel (Microsoft Corporation, Redmond, Washington): placebo followed by CBD treatment (PL-CBD) or CBD treatment followed by placebo (CBD-PL). After a 10–14 day baseline period, either placebo or CBD treatment was administered for 45 days depending on the patient's group allocation. Following the first phase of treatment, dogs underwent a 30-day washout period prior to receiving the opposite treatment for a subsequent 45 days (Figure 1). If the 45th day fell on a weekend or holiday, or the owner was unable to make the appointment day, treatment was continued until the morning of evaluation.

The study sponsor (cbdMD, Charlotte, NC, United States) provided the CBD and placebo oil in two identical bottles to the research team. The bottles were coded by an unblinded individual who did not participate in veterinary assessments (FD). The oil, containing a medium chain triglyceride (MCT) oil and peanut flavoring for scent masking and palatability, was packaged in light protected bottles. The CBD oil contained approximately 1,500 mg CBD per 30 mL bottle, confirmed via third party testing (SC Laboratories California LLC, Santa Cruz, CA). Quality assurance testing was performed on the batch and a certificate of analysis was provided by the company (Supplementary material). The concentration of CBD was within 5% and above the labeled dose which is within the margins of error in analytical laboratories. CBD oil was dosed at 5 mg/kg CBD *per os* every 12 h, and the placebo was dosed at equal volumes and time intervals. The CBD or placebo oil was dispensed to the owners in individual bottles with a syringe marked at the appropriate volume for administration. The bottles contained identical labels and instructions for dosing each patient. The owners and all personnel involved in patient evaluation were blinded to the contents of the bottle. Owners were instructed to administer treatments with a meal.

2.2 Clinical pathology

Whole blood was collected at follow-up visits #3–5 for biochemistry and plasma CBD analysis (Figure 1). Elevations in liver enzymes including ALP, ALT, AST, T-bilirubin, and GGT were recorded and classified as mild (greater than two-fold but less than six-fold) or moderate (greater than six-fold) (14). Additionally, the percent increase from baseline was calculated.

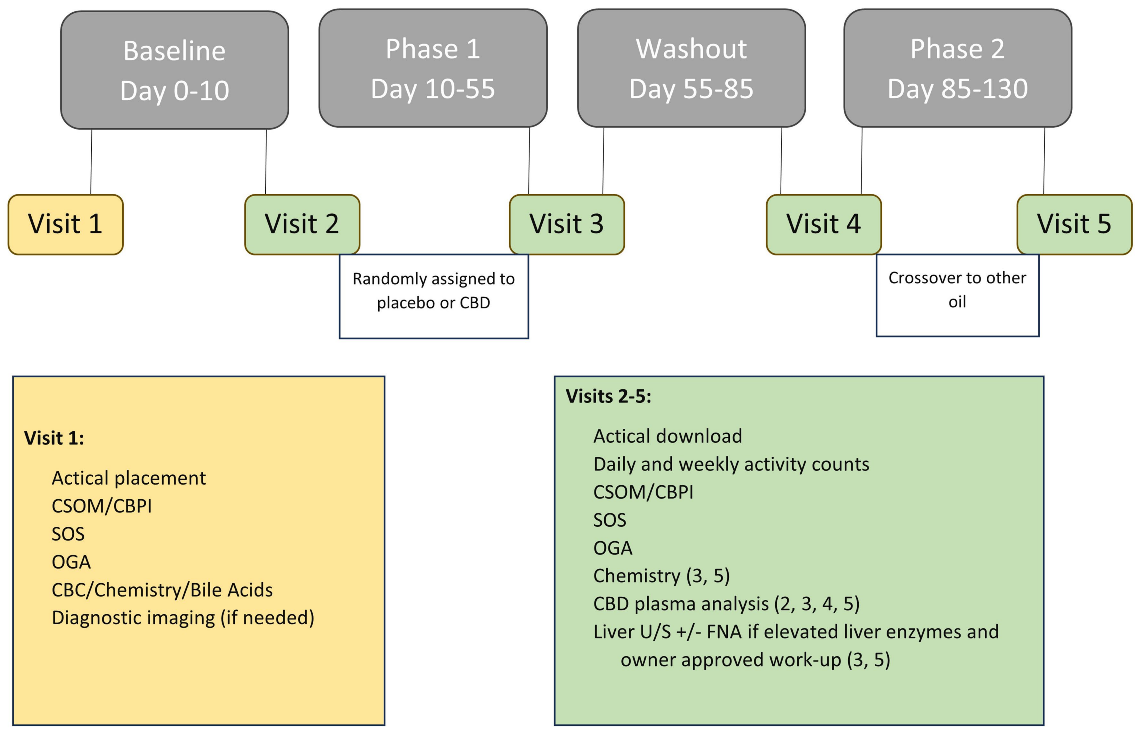

FIGURE 1
Overview of study timeline including data obtained at each visit, outcome measures, and any treatments administered at each phase.

2.3 Diagnostic hepatic ultrasound

If any liver enzyme elevations were noted, fasted bile acids in addition to a focused liver ultrasound and fine-needle aspirate were offered but not required. Hepatic ultrasounds were performed by a boarded radiologist or radiology resident under the direct supervision of a boarded radiologist. If changes were noted within the liver and owners consented, aspirates were collected and submitted for cytology. If necessary, dogs received 0.1 mg/kg butorphanol IV for hepatic ultrasound and aspirates. Findings on liver ultrasound and cytology were also documented.

2.4 Outcome measures

2.4.1 Clinical metrology instruments (CMIs)

CMIs including the canine brief pain inventory (CBPI) and client-specific outcome measures (CSOM) were completed by the owners at each visit (Supplementary material). Initial CMIs were discussed with the owner at the time of enrollment to ensure understanding of the questionnaires, and the same owner filled out the CMIs at follow-up visits via dependent interviewing (15). For the CSOM, owners were provided a list of examples for both the activity and behavior portions of the form. Specific examples pertaining to the pet were also discussed, but ultimately, the owner was allowed to choose each activity and behavior. Owners were requested to select five activities and three behaviors pertaining to their dog's mobility. For this reason, numeric indication of improvement could vary based on owner report of positive or negative behaviors. Values were adjusted for statistical analysis such that a higher numeric value indicated improvement for all patients regardless of reported behavior.

2.4.2 Veterinary assessments

Patients were evaluated by a veterinarian at each visit, and a previously published orthopedic scoring system was used to quantify exam findings (16). The subjective orthopedic scoring (SOS) consisted of six components each rated with a score 0–4 (0 = normal, 4 = severe impairment) and evaluated lameness at a walk and trot, pain on manipulation, offloading of the most affected limb, willingness to load the contralateral limb, and functional disability. The sum of the scoring for each category was used for analysis.

2.4.3 Accelerometry

All dogs enrolled in the study were fitted with an activity monitoring collar using the Actical (Respironics Mini Mitter Division, Bend, OR) collar as previously described (13). Monitoring was continuous throughout the study period with the epoch length set to 60 s. Data was downloaded at each visit to ensure activity was being recorded and battery life was sufficient. If there was damage to the device or errors in the download process, it was attempted to recover the data and a new Actical collar was placed on the dog. Otherwise, the same device was maintained for each pet throughout the study period.

2.4.4 Objective gait analysis

Gait analysis was performed at each visit using a pressure sensitive walkway (PSW) (6-Tile High Resolution Strideway System, Tekscan Inc., South Boston, MA). Dogs were evaluated at a trot in a similar fashion to a previously described protocol (13). If the dog was unable to trot, they were evaluated at a walk. Prior to data collection, dogs were acclimated to the gait analysis laboratory and leash walking with the handler on the right and left. Six trials (three in each direction) with a subjectively constant velocity, in a straight line, without lateralization of the head, pulling on the leash, or stepping off the PSW were acquired. When only a single direction was tolerated, the dog was walked in that direction for six valid trials. Trials at subsequent visits were only considered valid for the individual patient if they fell within 0.3 m/s of the velocity established at the baseline visit. The correct labeling of foot placement was confirmed by video analysis collected during gait acquisition. Percent body weight distribution (%BWD) was calculated and averaged for the six valid trials at each visit.

$$\%BWD = \frac{PVF\,[N]\,of\ the\ limb}{total\ PVF\,[N]\,of\ all\ four\ limbs\ in\ one\ gait\ cycle} x\,100$$

2.5 Statistical analysis

Sample size calculation was performed using SAS Proc Power (SAS 9.4, SAS Institute Inc., Cary, NC). The baseline data from a previous study ($n = 23$ dogs with mobility impairment due to arthritis) was used for a paired t-test (corresponding to the crossover design) with alpha = 0.05. Power calculation was performed based on CBPI PSS and PIS. For CBPI PSS, the power calculation was based on a meaningful difference of 1 with a conjectured standard deviation of 1.68. To achieve 80% power $n = 25$ dogs are required; to achieve 90% power $n = 32$ dogs are required. For CBPI PIS, the power calculation was based on a meaningful difference of 2 with a conjectured standard deviation of 2.10 (17). To achieve 90% power and account for attrition, a sample size of $n = 40$ was proposed.

The outcome measures, including CMIs, OGA, accelerometry, and liver enzymes, were analyzed using a linear mixed model (18). The model was fit separately for each response variable using the lme4 package within the R statistical software (R 4.0.2, R Core Team, Vienna, Austria) (19). Each individual dog was included as a random effect to account for repeated measures. Treatment (baseline, post-CBD, and post-placebo), period (pre- and post-washout), and period-by-treatment interaction were included as fixed effects to identify the changes in outcome measures from baseline to post-treatment (CBD or placebo), as well as potential period and carryover effects due to the crossover study design (18). For liver enzyme data, NSAID administration and its interaction with treatment were also included in the model as fixed effects. Estimated marginal means and contrasts were calculated using the emmeans package (41). The p-values associated with the treatment effects were calculated based on t-tests of the regression coefficients in the linear mixed model and were used to determine statistical significance. Following the recommendations of experts in medical statistics, no multiplicity adjustments were performed given the exploratory nature of the analyses (20). The p-values should be interpreted for descriptive purposes but not for confirmatory decision making. Residual diagnostic plots were used to evaluate model assumptions (normality and equal variance of random errors). A log transformation was deemed necessary for the activity counts and for the following liver enzyme measures: ALP, ALT, and AST. After necessary transformations, no obvious violations of modeling assumptions were identified, as seen from the evenly scattered residuals around the horizontal zero line.

A Mann–Whitney U test was used to compare CBD plasma levels to placebo levels since the data was not normally distributed.

3 Results

The number of surveys received, dogs evaluated, enrolled, and included for analysis is summarized in Figure 2. Forty-two dogs qualified for enrollment in the study. There were 21 each of neutered males and spayed females. Patient age ranged from 1 year to 15 years (median $n = 7.5$ years), and weight ranged from 15 kg to 68 kg (median $n = 29$ kg). Included breeds and the most clinically affected region are summarized in Table 1. Thirty-eight dogs completed the study. Two dogs were unenrolled after the owner elected withdrawal, one dog was euthanized for reasons unrelated to the study, and one dog was in a dog fight that resulted in a new lameness and exclusion from the remainder of the study. Two dogs who did not complete the study had data included until the time of withdrawal from the study. One dog who completed the study had all data removed after CBD plasma levels suggested inadvertent CBD administration during the placebo phase. In total, 39 dogs were included for at least partial analysis. Fourteen dogs had at least partial exclusion of data for which reasons are summarized in Table 1.

A summary of all subjective and objective outcome measures is reported in Tables 2, 3. Compared to baseline data, veterinary assessments ($p = 0.044$), CBPI ($p < 0.001$), CSOM ($p < 0.001$), and both moderate and total activity counts ($p = 0.033$ and $p = 0.046$, respectively) showed improved outcomes in dogs receiving CBD. Objective gait analysis percent body weight distribution data showed insufficient evidence of improvement for both the placebo and CBD groups ($p = 0.197$ and $p = 0.121$, respectively). The CBD group showed eight significant comparisons to baseline while the placebo group only showed three significant comparisons. The improvements seen in the placebo group compared to baseline confirm an expected caregiver placebo effect. However, there was insufficient evidence of improvement in veterinary assessments or objective outcome measures in the placebo group. Comparisons between groups found evidence of dogs receiving CBD showing improvement in veterinary assessments ($p = 0.046$), the pain severity scoring of CBPI ($p = 0.017$), and behavior scoring of CSOM ($p = 0.007$).

Seventeen dogs had elevations in at least one liver enzyme throughout the study (predominantly ALP), but one dog was excluded from analysis after starting corticosteroids for pemphigus foliaceus that resulted in elevated ALP following the washout period. Three patients with AST elevations, one of which also had a T-bilirubin elevation, without concurrent ALP and ALT elevations, had these single data points excluded from analysis as the sample was hemolyzed and these two markers can be affected by hemolysis (21). Characterization of the liver enzyme elevations and the associated treatment(s) are summarized in Table 4. Of the 14 patients with meaningful elevations included for analysis, 10 dogs were receiving CBD at the time of elevations, seven of which were concurrently receiving NSAIDs. Four dogs with elevations were receiving placebo and NSAID, but three of these dogs had received CBD first and continued to have elevations throughout the study, although these values were decreasing. Two dogs with elevated liver enzymes were receiving the placebo treatment alone. Both of these were ALT elevations and one dog's elevation started after receiving CBD and having elevations in both ALP and ALT, but the ALP elevation resolved. Changes in liver enzymes for patients receiving NSAIDs, CBD, and placebo and their comparisons are summarized in Tables 5, 6. Both patients receiving CBD alone and those receiving CBD and NSAID showed evidence of ALP elevations ($p < 0.001$ for all). Additionally, there was evidence that this increase in ALP was greater in dogs receiving CBD and NSAID compared to CBD alone ($p = 0.046$). For ALT, only patients receiving CBD and NSAID showed evidence of elevation compared to NSAID administration alone ($p = 0.022$ and $p = 0.025$). Of the patients with any elevation in liver enzymes, six owners consented to focused hepatic ultrasound and five to fine needle aspirates of the liver. Changes to the liver included glycogen accumulation ($n = 2$), vacuolar hepatopathy ($n = 5$), and mild lymphocytic inflammation ($n = 2$). One dog additionally had multifocal necrosis on cytology. This patient had a mildly elevated ALP at the time of enrollment with moderate elevation following CBD administration, and fasted bile acids at the time of that elevation that were within normal limits.

Side effects were uncommon but included gastrointestinal signs such as vomiting and diarrhea. Two dogs were reported to vomit on CBD alone, one dog on both CBD and placebo, and one dog was reported to have diarrhea on CBD. All gastrointestinal signs appeared to be self-limiting and resolved without further intervention and while continuing to receive the product.

Batch analysis was performed on both the CBD and placebo products before being dispensed (SC Laboratories California LLC, Santa Cruz California, USA). Certificate of analysis showed no detectable levels of THC, CBD, or other cannabinoids in the placebo product (Supplementary material). Per 30 mL unit, the CBD product contained a range of 1570.62 mg total CBD and 1585.86 mg total cannabinoids. This included 8.46 mg CBG and 3.87 mg CBDV. There were no detectable levels of THC. Both the CBD and placebo products were additionally tested for the presence of pesticides, residual solvents, mycotoxins, heavy metals, foreign material, and microbiological contaminants such as bacteria, yeast, and molds. Results were passing for both products across all measures.

Thirty-nine were included for plasma analysis. One dog was excluded because the owner withdrew during the first phase of administration, one dog was excluded for returning high CBD plasma values for both placebo and CBD treatment phases, raising the concern for inadvertent CBD administration, and one dog was excluded due to low levels throughout the study which may have been due to late timing of blood draws relative to last dose or owner non-compliance. Three dogs who did not complete the study were included for plasma analysis up until the point of unenrollment. All three of these dogs received the CBD oil first, so there were 36 placebo oil samples and 39 CBD oil samples included for analysis. There was one outlier value for the placebo and two

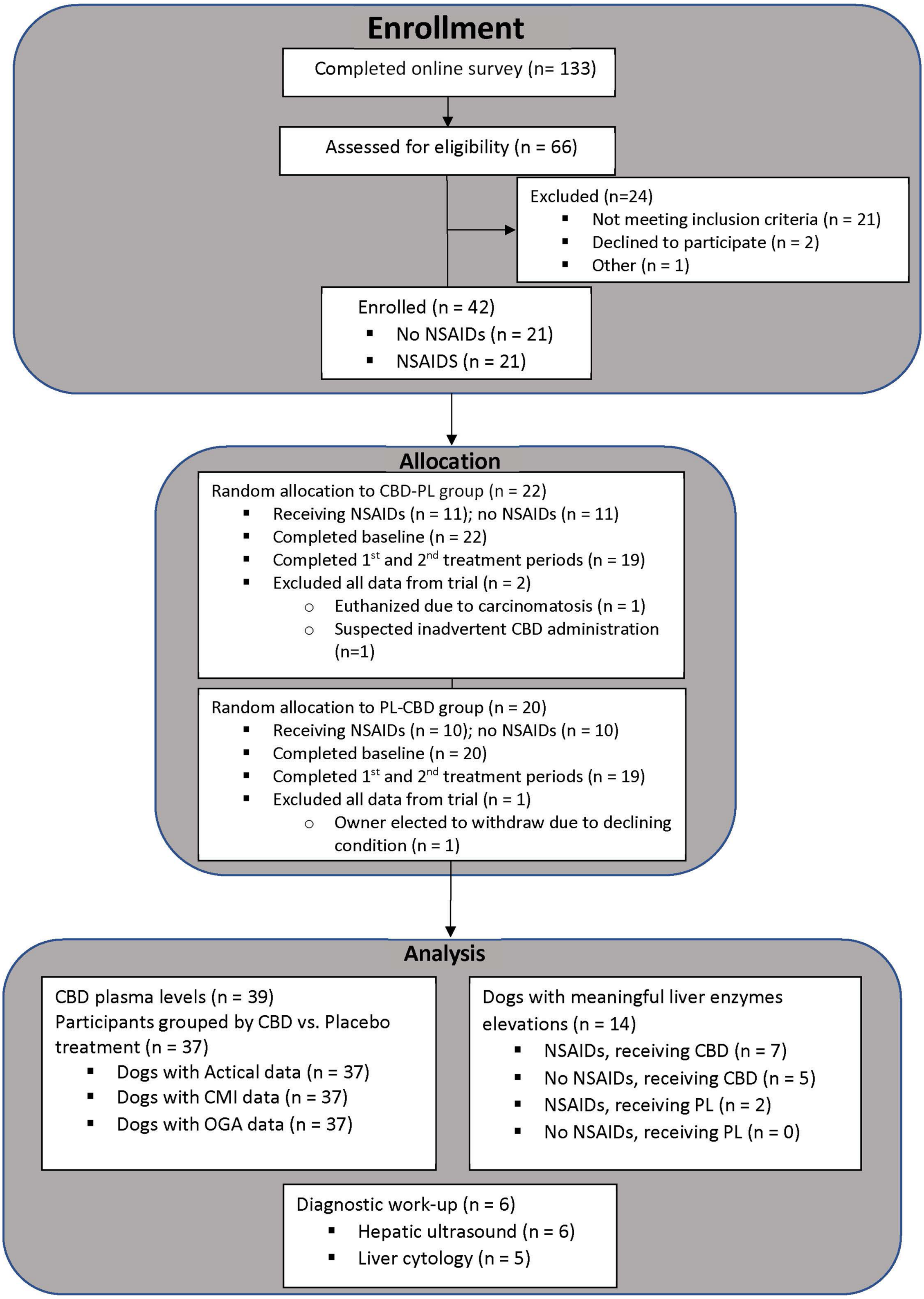

FIGURE 2
Number of participants at each phase of the clinical trial from the time of enrollment untill data analysis.

outlier values for the CBD oil samples. Outlier values were retested to confirm but ultimately included for analysis because the timing of blood draws relative to the last CBD dosing was not controlled for in this study and may have led to variation in sample values. The median CBD plasma level following the administration of CBD oil was 141.5 ng/mL (range 3.13–1850). The median for the

TABLE 1 Enrollment data including patient age, sex, breed, NSAID status, primary mobility disorder, sequence of treatment, and any reason for data exclusion.

Patient	Age	Sex	Breed	NSAID status	Diagnosis of most affected region	Sequence of treatment	Data exclusion
1	2	MN	Golden retriever	Carprofen	R elbow OA	PL-CBD	--
2	5	FS	Mixed breed	No NSAID	L stifle OA	PL-CBD	--
3	9	MN	Brittany spaniel	No NSAID	R gluteal tendinopathy	PL-CBD	--
4	9	MN	Border collie	No NSAID	R biceps tendinopathy	CBD-PL	Developed CCT injury, excluded visit #3–5
5	2	MN	Mixed breed	No NSAID	R hip OA	CBD-PL	--
6	15	FS	Norwegian elkhound	No NSAID	T3-L3 myelopathy	PL-CBD	Excluded all data, owner withdrawal after visit #3 due to declining condition
7	2	MN	Mixed breed	No NSAID	R carpal OA	PL-CBD	--
8	5	FS	Labrador retriever	No NSAID	L elbow OA	CBD-PL	--
9	2	FS	Mixed breed	No NSAID	R stifle OA	PL-CBD	--
10	12	FS	Labrador retriever	Carprofen	L hip OA	PL-CBD	--
11	7	FS	English bulldog	No NSAID	L elbow OA	CBD-PL	Data excluded at visits #4–5 due to new lameness
12	11	FS	Mixed breed	No NSAID	R biceps tendinopathy	PL-CBD	--
13	13	FS	Labrador retriever	Carprofen	L hip OA	CBD-PL	--
14	5	FS	American staffordshire terrier	Carprofen	R carpal OA	PL-CBD	Data excluded at visit #3 due to development of pododermatitis
15	2	FS	Belgian malinois	No NSAID	R hip OA	PL-CBD	--
16	9	FS	Labrador retriever	No NSAID	L shoulder OA	CBD-PL	--
17	7	FS	Mixed breed	No NSAID	LS disease	CBD-PL	Unenrolled from the study at visit #4 due to dog attack resulting in new lameness
18	11	MN	Mixed breed	Carprofen	L hip OA	CBD-PL	--
19	13	FS	Golden doodle	No NSAID	L hip OA	CBD-PL	Excluded all data, diagnosed with carcinomatosis during study and euthanized
20	5	FS	Mixed breed	Carprofen	L carpal OA	CBD-PL	Plasma CBD levels excluded due to low levels throughout study
21	10	MN	Labrador retriever	No NSAID	L shoulder OA	CBD-PL	Data excluded at visit #4–5 due to R shoulder injury while hunting
22	8	FS	Golden retriever	No NSAID	L proximal gastrocnemius tendinopathy	CBD-PL	--
23	2	MN	Mixed breed	Carprofen	R hip OA	CBD-PL	--
24	10	FS	Mixed breed	No NSAID	L carpal flexor tendinopathy	CBD-PL	Data excluded at visit #4–5 due to dog attack resulting in shoulder injury
25	10	MN	Mixed breed	No NSAID	LS disease	PL-CBD	Data excluded at visit #4–5 due to starting prednisone for pemphigus foliaceous
26	7	MN	Mixed breed	No NSAID	L biceps tendinopathy	CBD-PL	--
27	9	FS	Mixed breed	Carprofen	L biceps tendinopathy	CBD-PL	Data excluded at visit #3–5 due to R shoulder injury
28	10	MN	Mixed breed	Carprofen	R elbow OA	CBD-PL	--
29	5	MN	Bernese mountain dog	Carprofen	R elbow OA	PL-CBD	Data excluded at visit #3 due to deviation from protocol – stopped NSAID administration for 1 week

(Continued)

TABLE 1 (Continued)

Patient	Age	Sex	Breed	NSAID status	Diagnosis of most affected region	Sequence of treatment	Data exclusion
30	9	MN	Mixed breed	Carprofen	R hip OA	PL-CBD	Excluded visit #3–5, developed HGE and hospitalized
31	1	MN	Mixed breed	No NSAID	R elbow OA	PL-CBD	--
32	6	MN	Mixed breed	Carprofen	R elbow OA	CBD-PL	--
33	14	FS	Golden retriever	Carprofen	L stifle OA	CBD-PL	Excluded visit #5 due to R full CCL tear. CBD Plasma data excluded for low CBD levels at baseline
34	3	MN	Labrador retriever	Carprofen	L stifle OA	PL-CBD	--
35	11	FS	Mixed breed	Carprofen	R stifle OA	PL-CBD	--
36	10	MN	Border collie	None	L hip OA	PL-CBD	--
37	2	MN	American staffordshire terrier	Carprofen	L tarsal OA	PL-CBD	--
38	10	MN	Labrador retriever	Carprofen	R shoulder OA	PL-CBD	--
39	2	FS	German shepherd dog	Carprofen	R elbow OA	PL-CBD	--
40	9	MN	Australian shepherd	Carprofen	LS disease	CBD-PL	Excluded visit #5 due to significant increase in activity and change in medications
41	1	FS	Mixed breed	Carprofen	L Hip OA	CBD-PL	Unenrolled at visit #4 due to owner withdrawal
42	2	MN	Mixed breed	Carprofen	R carpal desmopathy and tendinopathy	CBD-PL	All data excluded due to suspected inadvertent CBD administration throughout trial

CBD, cannabidiol oil; PL, placebo oil.

placebo oil was below the level of quantification (BLOQ) at <0.98 ng/mL (range BLOQ-104). There was a statistically significant difference between CBD plasma levels compared to placebo levels ($p < 0.001$).

4 Discussion

This double-blind, crossover, placebo-controlled study was conducted to evaluate the effect of CBD in client-owned dogs with mobility disorders as well as provide more information regarding patient tolerance when co-administered with NSAIDs. For clinical relevance, this study sought to evaluate the effect of CBD on pain and function in dogs, so enrollment was expanded to all mobility impairments and not limited to just those with osteoarthritis, although the most common diagnosis in the enrolled patients. To address some of the limitations of prior studies, both subjective and objective outcome measures were used to assess dogs in a crossover design. The study results suggest a potential therapeutic benefit of CBD administration for the management of mobility impairments, as well as patient tolerance when co-administered with NSAIDs in dogs.

Several previous studies evaluating CBD for pain conditions have also found improvements in CMIs, but a recent systematic review and meta-analysis of CBD literature for canine OA found a high risk of bias in the available literature (11). Dogs in the present study with pain related to mobility impairments showed improvement in both the CBD and placebo groups. The observed improvement in the placebo group is likely attributed to an expected caregiver placebo effect which has been reported to occur up to 57% of the time when owners or veterinarians observe a dog's lameness (22). When comparing treatment groups, however, only the CBD group showed improvement in veterinary assessments, pain severity scores, and client-specific behavior scores. Furthermore, blinded veterinary assessments showed improvements in the CBD group but not in the placebo group. The combination of these findings may indicate a positive effect of CBD on pain and function.

Objectively, this study used both a pressure sensitive walkway and accelerometry to assess dogs after administration of placebo and CBD oil. Objective gait analysis (OGA) did not show improvement in this study, but objective gait analysis is not without its limitations. While several trials were collected for each dog during each return visit, the data could theoretically be influenced by outside factors such as the dog's activity level prior to data collection and anxiety in hospital. Kinetic data can also be influenced by factors such as walking versus trotting, the number of trials collected, handler, velocity, and acceleration (23). While the velocity for valid trials needed to be within 0.3 m/s to be considered a valid trial, acceleration was not controlled in this study.

Because gait analysis measurements occur in the hospital setting during this singular time frame at each visit, a second objective means

TABLE 2 Client metrology instruments (CMI) as means and standard error and differences between baseline, placebo and CBD for each including CBPI (PSS, PIS, QoL), CSOM (ACT, BEHAV).

CMI	Treatment	Baseline and post-treatment CMI score, Mean ± SE	Post-Treatment CMI score comparison, difference ± SE	*P* value comparing between treatments
↓SOS Total (0–24)	Baseline	9.81 ± 0.55	Placebo-baseline 0.23 ± 0.28	0.411
	Placebo	10.04 ± 0.60	CBD – Baseline −0.55 ± 0.27	0.044 *
	CBD	9.27 ± 0.59	CBD – Placebo −0.78 ± 0.39	0.046 *
↓CBPI PSS (0–10)	Baseline	4.11 ± 0.23	Placebo-baseline −0.34 ± 0.23	0.143
	Placebo	3.79 ± 0.32	CBD – Baseline −1.10 ± 0.22	0.000 *
	CBD	3.05 ± 0.31	CBD – Placebo −0.77 ± 0.32	0.017 *
↓CBPI PIS (0–10)	Baseline	5.21 ± 0.27	Placebo – baseline −0.98 ± 0.32	0.002 *
	Placebo	4.23 ± 0.37	CBD- baseline −1.33 ± 0.31	0.000 *
	CBD	3.88 ± 0.37	CBD – Placebo −0.35 ± 0.43	0.417
↑ CBPI QOL (0–5)	Baseline	3.29 ± 0.11	Placebo – baseline 0.24 ± 0.13	0.061
	Placebo	3.53 ± 0.15	CBD- baseline 0.47 ± 0.12	0.000 *
	CBD	3.77 ± 0.15	CBD – Placebo 0.24 ± 0.17	0.169
↓CSOM ACT (1–5)	Baseline	3.01 ± 0.11	Placebo – baseline −0.36 ± 0.14	0.013 *
	Placebo	2.64 ± 0.16	CBD- baseline −0.61 ± 0.14	0.000 *
	CBD	2.39 ± 0.16	CBD – Placebo −0.25 ± 0.20	0.206
↑ CSOM BEHAV (1–5)	Baseline	1.99 ± 0.11	Placebo – baseline 0.46 ± 0.16	0.004 *
	Placebo	2.45 ± 0.17	CBD- baseline 1.04 ± 0.15	0.000 *
	CBD	3.03 ± 0.16	CBD – Placebo 0.58 ± 0.21	0.007 *

CBD, cannabidiol; SOS, subjective orthopedic scoring; CBPI, canine brief pain inventory; CMI, clinical metrology instrument; PSS, pain severity score; PIS, pain interference score; QOL, quality of life; CSOM, client subjective outcome measure; ACT, activity; BEHAV, behavior. Direction of arrow next to listed CMIs denotes the direction of value which indicates a more favorable response (i.e., ↓ represents that a lower score equates to clinical improvement and vice versa).

of measuring response to CBD was selected in this study to provide more broad information regarding a dog's activity changes at home over a longer period of time. Dogs in this study showed a significant increase in both moderate and total activity counts when receiving CBD oil compared to baseline. While accelerometry may provide more information regarding a dog's activity over time, the output values can be influenced by factors such as erroneous reading from collar loosening, equipment malfunction, or scratching at the collar and device. It has also been suggested that the use of accelerometry as an outcome measure in clinical research is questionable as it is easily influenced by owner behaviors (increase or decrease in activity base on perceived or desired outcome) rather than a true representation of changes in pain (13). When considering changes in activity counts, however, an increase in activity by 20% was clinically relevant when accelerometry was used to measure differences in dogs with naturally occurring OA treated with carprofen versus a placebo (24). Percent increase in total activity count for the CBD group in this study approached this value (18.98% ± 10.16%) which may further support the use of CBD for the management of mobility disorders in dogs.

The dose of CBD may also contribute to the improvements seen across outcome measures in this study compared to others. Previous studies evaluating the efficacy of CBD oil for the management of pain disorders suggest a dose range of 4–5 mg/kg/day (13, 25–27). The present study used a higher dose of CBD at 10 mg/kg/day (5 mg/kg q12h). Despite higher doses, however, the observed CBD plasma concentrations in this study were similar to previously reported values, but they did show a greater range of values (26). Therapeutic plasma levels do not appear to be well established in the literature, and plasma levels may be greatly influenced by several factors such as variable absorption between patients, variations in the CBD oil product, and the timing of blood draws relative to dosing. One major limitation regarding the measurement of plasma CBD levels in this study is the timing of blood draw relative to last dosing. Owners were instructed to administer the oil the morning of the appointment, but the time of morning feeding and time of blood draw varied between patients and likely contributed to variability in plasma concentrations. While pharmacokinetics can differ between CBD products, a recent pharmacokinetic study measured CBD concentrations over a 24-h period after administration in a population of healthy laboratory beagles that revealed changes in CBD concentration over time with peak concentrations occurring around two hours after administration (28). Another study found an elimination half-life of 4.2 h at both 2 mg/kg and 8 mg/kg dosing (26). Given this information, the timing of blood draw relative to the last CBD dose likely had an impact on CBD concentrations and the variation noted. While most blood draws in this study occurred in the morning, theoretically within a few hours of CBD administration, this variable, along with timing of administration, was not controlled for in this study and should be considered in future studies. Additionally, this CBD product was considered a broad-spectrum rather than full-spectrum

TABLE 3 Objective outcome measures represented by means and standard error and differences between baseline, placebo, and CBD including activity and percent body weight distribution.

Objective measure	Treatment	Baseline and post-treatment, Mean $\pm$ SE	Post-treatment, difference $\pm$ SE	*P* value comparing between treatments
↑ OGA.BWD	Baseline	21.80 ± 0.95	Placebo-baseline 0.51 ± 0.39	0.197
	Placebo	22.31 ± 1.01	CBD – Baseline 0.61 ± 0.39	0.121
	CBD	22.41 ± 1.01	CBD – Placebo 0.10 ± 0.55	0.853
↓Actical.SED	Baseline	1109.75 ± 23.40	(Placebo-baseline)/Baseline −0.14% ± 1.17%	0.903
	Placebo	1108.17 ± 25.31	(CBD – Baseline)/Baseline −0.86% ± 1.07%	0.427
	CBD	1100.22 ± 24.98	(CBD – Placebo)/Baseline −0.72% ± 1.57%	0.651
↓Actical.Light	Baseline	171.29 ± 9.23	(Placebo-baseline)/Baseline 4.12% ± 4.02%	0.300
	Placebo	178.35 ± 10.90	(CBD – Baseline)/Baseline −3.99% ± 3.42%	0.258
	CBD	164.47 ± 9.96	(CBD – Placebo)/Baseline −7.78% ± 4.80%	0.125
↑ Actical.MOD	Baseline	109.53 ± 9.69	(Placebo-baseline)/Baseline −0.28% ± 6.90%	0.968
	Placebo	109.22 ± 11.20	(CBD – Baseline)/Baseline 14.98% ± 7.36%	0.033 *
	CBD	125.94 ± 12.78	(CBD – Placebo)/Baseline 15.30% ± 10.76%	0.132
↑ Actical.VIG	Baseline	0.48 ± 0.23	(Placebo-baseline)/Baseline 9.49% ± 12.50%	0.430
	Placebo	0.62 ± 0.29	(CBD – Baseline)/Baseline −3.26% ± 10.20%	0.754
	CBD	0.43 ± 0.25	(CBD – Placebo)/Baseline −11.65% ± 13.61%	0.424
↑ Total activity count	Baseline	$1.17\times10^5 \pm 1.36\times10^4$	(Placebo-baseline)/Baseline 3.71% ± 9.58%	0.695
	Placebo	$1.21\times10^5 \pm 1.64\times10^4$	(CBD – Baseline)/Baseline 18.98% ± 10.16%	0.046 *
	CBD	$1.39\times10^5 \pm 1.86\times10^4$	(CBD – Placebo)/Baseline 14.73% ± 14.28%	0.274

OGA, objective gait analysis; BWD, body weight distribution; SED, sedentary; MOD, moderate; VIG, vigorous. Direction of arrow next to listed CMIs denotes the direction of value which indicates a more favorable response (i.e., ↓ represents that a lower score equates to clinical improvement and vice versa).

TABLE 4 Case evaluation of dogs with hepatic enzyme elevations including percent ALP increase from baseline, treatment(s) at the time of elevation, hepatic ultrasound findings, hepatic cytology, and other notable changes.

Patient	% Inc ALP from baseline	Treatment(s)	Hepatic ultrasound findings	Hepatic cytology	Other notes
3	100%	CBD	Hyperechoic and coarse liver	Glycogen accumulation	Bile acids: 5 umol/L, resolved at follow up
5	N/A – ALT elevation only	Placebo	Ultrasound not performed	Not performed	Resolved at follow up
13	178%	CBD, carprofen	Mildly heterogenous hepatic parenchyma with new hyperechoic nodule	Mild–moderate hepatocellular vacuolation. Multifocal necrosis	Bile acids: 3 umol/L, ALP elevation at enrollment
14	450%	CBD, carprofen	Ultrasound not performed	Not performed	ALP 143 U/L (ref 15–140)
16	255%	CBD	Normal liver	Vacuolar hepatopathy	Bile acids 5 umol/L, ALT elevations, resolved at follow up
22	645%	CBD	Ultrasound not performed	Not performed	Resolved at follow up
23	404%	CBD, carprofen	Ultrasound not performed	Not performed	Resolved at follow up
29	N/A – ALT elevation only	Placebo, carprofen	Ultrasound not performed	Not performed	ALT 99 U/L, resolved at follow up
30	4,445%	CBD, carprofen	Mild benign change (ie vacuolar hepatopathy)	Not performed	Resolved at follow up
33	1,919%	CBD, carprofen	Non-specific, likely chronic, hepatopathy and solitary hypo- to isoechoic nodule	Moderate to marked hepatocellular vacuolization, mild lymphocytic inflammation	ALT 117 U/L
35	1,327%	CBD, carprofen	Ultrasound not performed	Not performed	
36	1,673%	CBD	Diffusely hyperechoic hepatic parenchyma with multiple hyperechoic nodules	Vacuolar hepatopathy w/ mild lymphocytic inflammation	ALT 100 U/L, all elevations resolved at follow up
40	1,392%	CBD, carprofen	Ultrasound not performed	Not performed	ALT 123 U/L

TABLE 5 Hepatic enzymes represented as means and standard error for each treatment combination measured for ALP, ALT, AST, T-bilirubin, and GGT as well as the number of dogs above the reference range for each hepatic enzyme for each treatment combination.

Hepatic Enzyme	Treatment(s)	# Dogs above reference range	Mean	SE
ALP (U/L)	Baseline & NSAID	2	43.96	9.48
	Placebo & NSAID	3	41.39	10.01
	CBD & NSAID	7	154.12	37.89
	Baseline	0	37.35	8.26
	Placebo	0	31.24	7.95
	CBD	3	80.28	19.65
ALT (U/L)	Baseline & NSAID	0	40.58	3.75
	Placebo & NSAID	3	38.60	4.05
	CBD & NSAID	2	48.80	5.22
	Baseline	0	36.91	3.50
	Placebo	2	34.91	3.87
	CBD	1	39.61	4.21
AST (U/L)	Baseline & NSAID	0	25.24	1.29
	Placebo & NSAID	0	26.02	1.60
	CBD & NSAID	0	28.36	1.79
	Baseline	0	26.04	1.36
	Placebo	0	25.96	1.70
	CBD	1	27.91	1.72
T-bilirubin (mg/dL)	Baseline & NSAID	0	0.12	0.01
	Placebo & NSAID	0	0.11	0.01
	CBD & NSAID	0	0.10	0.01
	Baseline	0	0.13	0.01
	Placebo	0	0.10	0.01
	CBD		0.09	0.01
GGT (U/L)	Baseline & NSAID	0	1.16	0.25
	Placebo & NSAID	0	0.62	0.34
	CBD & NSAID	0	0.96	0.35
	Baseline	0	0.94	0.26
	Placebo	0	0.85	0.37
	CBD	0	1.03	0.34

product and contained no reported cannabidiolic acid (CBDA) which may have influenced outcomes as CBDA is thought to be more bioavailable and may aid in the absorption of CBD (28). Product differences likely exist between the different formulations (e.g., broad-spectrum, full-spectrum, isolates) and even within different products of the same formulation. This highlights the importance of testing different products and formulations for tolerability and absorption through plasma levels. Owner compliance may have also influenced the variation of CBD plasma values. A previous study evaluating owner compliance with veterinary prescribed therapeutics found 68% of owners missed at least one dose while 14% missed a significant proportion of doses, giving less than 60% as reported by electronic monitoring. Despite having electronic monitors, these owners were also likely to self-report perfect compliance while missing at least one dose (29).

Given that NSAIDs are a common treatment for pain and may also result in liver enzyme elevations, this study sought to further evaluate patient clinical tolerance when co-administered with CBD. Previous studies have evaluated CBD safety and efficacy while allowing dogs to remain on regular NSAID therapy, but these studies did not group dogs based on their NSAID administration (13, 25, 26). Administration of CBD oil has previously been shown to result in ALP elevations in both humans and dogs, and that association was also seen in this study in both dogs on CBD and NSAID combined as well as CBD alone (26, 27, 30–34). This ALP elevation is thought to be related to the induction of cytochrome P-450 oxidative metabolism (35, 36). Interestingly, five patients in this study also had mild ALT elevations following administration of CBD. Only one of these patients had ALP elevations at the time of enrollment. Elevations in ALT were reported in a recently published article for the management of epilepsy, but this appears to be the only report in veterinary literature apart from the present study (34). As in that study, a higher dose of CBD was given here compared to the 1-2 mg/kg twice daily dosing used in most other clinical studies. While the higher doses of CBD used in this study may account for the elevations seen in ALT, a prior study evaluating high doses of CBD (10 mg/kg/day and 20 mg/kg/day) given for 6-weeks in 30 healthy beagle dogs that found no clinically significant changes in serum biochemistry parameters other than elevations in ALP (33). In this study, however, only binary statistics were performed to evaluate rises in ALP greater than a 2-fold increase from baseline. Smaller elevations in ALP, such as was evaluated in the present study, were not documented. Another recent study administered CBD at doses of 2 mg/kg and 4 mg/kg twice daily for two weeks and found no ALT elevations and ALP elevations in only 3/16 dogs receiving CBD at 4 mg/kg (37).

The present study evaluated the effect of CBD co-administered with NSAIDs and its effect on liver enzymes. Only dogs receiving CBD and NSAID together showed evidence of ALT increases. There was also evidence of greater increases in AL*P* values for patients receiving NSAIDs and CBD together compared to patients receiving CBD alone. In the study by Rozental et al., CBD was also associated with an increase in ALT when used in combination with other anti-epileptic drugs. While direct drug comparisons cannot be made between this study and the present, both phenobarbital and NSAIDs have been associated with liver enzyme elevations (38, 39). Findings from this previous study and the present may suggest interaction of CBD with other drugs to influence liver enzymes. To the authors' knowledge, no present study exists in human or veterinary literature seeking to understand the effects of CBD and NSAID co-administration on liver enzyme elevations and its clinical relevance.

Of the patients in the present study who had liver enzyme elevations, five underwent further work-up of the liver with no apparent liver damage noted on ultrasound, cytology, or fasted bile acids testing. Three patients who returned to the teaching hospital one to six months after completion, for reasons unrelated to the study,

TABLE 6 Comparisons of hepatic enzyme changes represented as a mean percentage increase, standard error, and differences for ALP, ALT, AST, T-bilirubin, and GGT.

Hepatic Enzyme	Comparison of Differences	Mean % Increase	SE	P-Value
ALP	(Placebo & NSAID - Baseline & NSAID) / Baseline & NSAID	−5.85	16.01	0.724
	(CBD & NSAID - Baseline & NSAID) / Baseline & NSAID	250.56		0.000 *
	(CBD & NSAID - Placebo & NSAID) / Placebo & NSAID	272.34	60.93	0.000 *
	(Placebo - Baseline) / Baseline	−16.37	84.56	0.324
	(CBD - Baseline) / Baseline	114.93	15.10	0.000 *
	(CBD - Placebo) / Placebo	156.99	36.34	0.000 *
	(Baseline & NSAID - Baseline) / Baseline	17.70	59.16	0.590
	(Placebo & NSAID - Placebo) / Placebo	32.50	35.28	0.383
	(CBD & NSAID - CBD) / CBD	91.98	42.34	0.046 *
ALT	(Placebo & NSAID - Baseline & NSAID) / Baseline & NSAID	−4.87	7.38	0.521
	(CBD & NSAID - Baseline & NSAID) / Baseline & NSAID	20.27	9.53	0.022 *
	(CBD & NSAID - Placebo & NSAID) / Placebo & NSAID	26.43	13.05	0.025 *
	(Placebo - Baseline) / Baseline	−5.42	7.79	0.500
	(CBD - Baseline) / Baseline	7.32	8.28	0.362
	(CBD - Placebo) / Placebo	13.48	11.88	0.229
	(Baseline & NSAID - Baseline) / Baseline	9.93	14.08	0.464
	(Placebo & NSAID - Placebo) / Placebo	10.57	15.22	0.469
	(CBD & NSAID - CBD) / CBD	23.19	16.89	0.134
AST	(Placebo & NSAID - Baseline & NSAID) / Baseline & NSAID	3.07	5.67	0.583
	(CBD & NSAID - Baseline & NSAID) / Baseline & NSAID	12.35	6.39	0.040 *
	(CBD & NSAID - Placebo & NSAID) / Placebo & NSAID	9.00	7.79	0.230
	(Placebo - Baseline) / Baseline	−0.30	5.83	0.959
	(CBD - Baseline) / Baseline	7.20	5.85	0.206
	(CBD - Placebo) / Placebo	7.52	7.81	0.320
	(Baseline & NSAID - Baseline) / Baseline	−3.06	6.69	0.655
	(Placebo & NSAID - Placebo) / Placebo	0.22	7.84	0.977
	(CBD & NSAID - CBD) / CBD	1.60	7.83	0.838
T-bilirubin	(Placebo & NSAID - Baseline & NSAID) / Baseline & NSAID	−0.01	0.01	0.403
	(CBD & NSAID - Baseline & NSAID) / Baseline & NSAID	−0.02	0.01	0.144
	(CBD & NSAID - Placebo & NSAID) / Placebo & NSAID	−0.01	0.02	0.597
	(Placebo - Baseline) / Baseline	−0.03	0.01	0.018 *
	(CBD - Baseline) / Baseline	−0.04	0.01	0.002 *
	(CBD - Placebo) / Placebo	−0.01	0.02	0.672
	(Baseline & NSAID - Baseline) / Baseline	−0.01	0.01	0.401
	(Placebo & NSAID - Placebo) / Placebo	0.01	0.01	0.427
	(CBD & NSAID - CBD) / CBD	0.01	0.01	0.487
GGT	(Placebo & NSAID - Baseline & NSAID) / Baseline & NSAID	−0.53	0.39	0.169
	(CBD & NSAID - Baseline & NSAID) / Baseline & NSAID	−0.20	0.39	0.620
	(CBD & NSAID - Placebo & NSAID) / Placebo & NSAID	0.34	0.47	0.475
	(Placebo - Baseline) / Baseline	−0.10	0.41	0.812
	(CBD - Baseline) / Baseline	0.09	0.39	0.818
	(CBD - Placebo) / Placebo	0.19	0.48	0.699
	(Baseline & NSAID - Baseline) / Baseline	0.21	0.31	0.502
	(Placebo & NSAID - Placebo) / Placebo	−0.22	0.41	0.586
	(CBD & NSAID - CBD) / CBD	−0.07	0.41	0.858

all had normal liver enzyme values on follow up serum biochemistry. Two of these three patients were receiving NSAIDs. This would suggest the increase in ALT associated with CBD administration did not persist following cessation of the CBD. This is similar to findings in a recent safety study in which ALP elevations normalized in healthy dogs within 4 weeks of treatment cessation (30). Owners in the present study were given the option to pursue further work-up of the liver if enzyme elevations were noted, but many declined for reasons such as prolonged appointment time and possible necessity for sedation to obtain ultrasound images and/or aspirates. Another limitation of the liver work-up is the lack of long-term follow-up, and the absence of post-prandial bile acids. Therefore, limited conclusions can be drawn about the clinical significance of these liver enzyme changes with CBD and NSAIDs used together. Future studies may consider more extensive assessment of the liver to better understand the relationship between CBD use and liver enzyme elevations.

Apart from liver enzyme elevations, the only other reported adverse effect was self-limiting gastrointestinal signs. This occurred in approximately 10% of patients and required no further intervention. Of the dogs reporting GI symptoms, two were receiving NSAIDs but only reported side effects when receiving CBD. The one patient reported to vomit on both CBD and placebo oil had a history of intermittent gastrointestinal signs and was not receiving an NSAID at the time of the study. These study results suggest the co-administration of CBD and NSAIDs appears well tolerated with regard to GI side effects, but increases in liver enzymes were seen when dogs were receiving CBD and NSAID together that were greater than CBD or NSAID administration alone. Further studies are needed evaluating long term co-administration of NSAIDs and CBD before conclusions can be drawn regarding the safety of co-administration.

Given the efficacy of NSAIDs, this could be considered a confounding factor for the improvements seen across outcome measures, but the crossover design of this study sought to eliminate it as such. By enrolling dogs receiving NSAIDs consistently, as well as enrolling dogs not receiving NSAIDs, this study was able to evaluate the effects of co-administration with CBD oil. By setting the inclusion criteria of a consistent management protocol for mobility impairments and implementing a crossover design in which each patient received both CBD and placebo, we sought to eliminate the confounding factors of NSAIDs, nutraceuticals, and other pain medications.

The study results suggest a potential therapeutic benefit of CBD administration for the management of mobility impairments, however, there appeared to be an increase in ALP and ALT values in patients receiving CBD and NSAID together. While no other adverse events occurred related to the co-administration of NSAIDs and CBD, the sample size in this population is small and limits definitive conclusions. Future studies should evaluate bile acids, hepatic ultrasound, and ideally liver biopsy of patients with elevated liver enzymes following the co-administration of CBD and NSAIDs. Long term studies assessing the effect of CBD on mobility disorders in dogs are needed.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal studies were approved by the Clinical Review Board of Colorado State University (IACUC: #1608, initial approval 4/1/2021). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

BT: Data curation, Investigation, Writing – original draft, Writing – review & editing. LE: Investigation, Supervision, Writing – review & editing. SM: Investigation, Writing – review & editing, Conceptualization, Methodology. TZ: Formal analysis, Writing – review & editing. CW: Writing – review & editing, Methodology. FD: Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. Funding for the study was provided by the CBDMD.

Acknowledgments

The authors would like to thank the Orthopedic Medicine and Mobility Clinical Trials team for their assistance with data collection.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2024.1449343/full#supplementary-material

References

1. Frye C, Carr BJ, Lenfest M, Miller A. Canine geriatric rehabilitation: considerations and strategies for assessment, functional scoring, and follow up. *Front Vet Sci*. (2022) 9:2458. doi: 10.3389/fvets.2022.842458

2. O'Neill DG, Coulson NR, Church DB, Brodbelt DC. Demography and disorders of German shepherd dogs under primary veterinary care in the UK [journal article]. *Canine Genet Epidemiol*. (2017) 4:7. doi: 10.1186/s40575-017-0046-4

3. Monteiro-Steagall B, Steagall P, Lascelles B. Systematic review of nonsteroidal anti-inflammatory drug-induced adverse effects in dogs. *J Vet Intern Med*. (2013) 27:1011–9. doi: 10.1111/jvim.12127

4. Belshaw Z, Asher L, Dean RS. The attitudes of owners and veterinary professionals in the United Kingdom to the risk of adverse events associated with using non-steroidal anti-inflammatory drugs (NSAIDs) to treat dogs with osteoarthritis. *Prev Vet Med*. (2016) 131:121–6. doi: 10.1016/j.prevetmed.2016.07.017

5. Aghighi SA, Tipold A, Piechotta M, Lewczuk P, Kästner SB. Assessment of the effects of adjunctive gabapentin on postoperative pain after intervertebral disc surgery in dogs. *Vet Anaesth Analg*. (2012) 39:636–46. doi: 10.1111/j.1467-2995.2012.00769.x

6. Donati PA, Tarragona L, Franco JVA, Kreil V, Fravega R, Diaz A, et al. Efficacy of tramadol for postoperative pain management in dogs: systematic review and meta-analysis. *Vet Anaesth Analg*. (2021) 48:283–96. doi: 10.1016/j.vaa.2021.01.003

7. Landa L, Trojan V, Demlova R, Jurica J, Hrib R. Cannabidiol and the possibilities of its use in veterinary medicine of dogs and horses: a brief review. *Vet Med*. (2022) 67:455–62. doi: 10.17221/127/2021-vetmed

8. O'Brien TJ, Berkovic SF, French JA, Messenheimer JA, Sebree TB, Bonn-Miller MO, et al. Adjunctive transdermal Cannabidiol for adults with focal epilepsy: a randomized clinical trial. *JAMA Netw Open*. (2022) 5:e2220189. doi: 10.1001/jamanetworkopen.2022.20189

9. Bridgeman MB, Abazia DT. Medicinal Cannabis: history, pharmacology, and implications for the acute care setting. *P t*. (2017) 42:180–8.

10. Barbeau-Grégoire M, Otis C, Cournoyer A, Moreau M, Lussier B, Troncy E. A 2022 systematic review and Meta-analysis of enriched therapeutic diets and nutraceuticals in canine and feline osteoarthritis. *Int J Mol Sci*. (2022) 23:384. doi: 10.3390/ijms231810384

11. Patikorn C, Nerapusee O, Soontornvipart K, Lawonyawut K, Musikpodok K, Waleethanaphan K, et al. Efficacy and safety of cannabidiol for the treatment of canine osteoarthritis: a systematic review and meta-analysis of animal intervention studies. *Front Vet Sci*. (2023) 10:1248417. doi: 10.3389/fvets.2023.1248417

12. Ukai M, McGrath S, Wakshlag J. The clinical use of cannabidiol and cannabidiolic acid-rich hemp in veterinary medicine and lessons from human medicine. *J Am Vet Med Assoc*. (2023) 261:623–31. doi: 10.2460/javma.23.02.0064

13. Mejia S, Duerr FM, Griffenhagen G, McGrath S. Evaluation of the effect of Cannabidiol on naturally occurring osteoarthritis-associated pain: a pilot study in dogs. *J Am Anim Hosp Assoc*. (2021) 57:81–90. doi: 10.5326/jaaha-ms-7119

14. Ettinger SJ, Fedlman EC, Cote E. Textbook of veterinary internal medicine: Diseases of the dog and cat. St. Louis, MO, USA: Elsevier (2017).

15. Muller C, Gaines B, Gruen M, Case B, Arrufat K, Innes J, et al. Evaluation of clinical metrology instrument in dogs with osteoarthritis. *J Vet Intern Med*. (2016) 30:836–46. doi: 10.1111/jvim.13923

16. Baker-Meuten A, Wendland T, Shamir SK, Hess AM, Duerr FM. Evaluation of acupuncture for the treatment of pain associated with naturally-occurring osteoarthritis in dogs: a prospective, randomized, placebo-controlled, blinded clinical trial. *BMC Vet Res*. (2020) 16:357. doi: 10.1186/s12917-020-02567-1

17. Brown DC, Boston RC, Coyne JC, Farrar JT. Ability of the canine brief pain inventory to detect response to treatment in dogs with osteoarthritis. *J Am Vet Med Assoc*. (2008) 233:1278–83. doi: 10.2460/javma.233.8.1278

18. Lim CY, In J. Considerations for crossover design in clinical study. *Korean J Anesthesiol*. (2021) 74:293–9. doi: 10.4097/kja.21165

19. Bates D, Mächler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. *J Stat Softw*. (2015) 67:1–48. doi: 10.18637/jss.v067.i01

20. Bender R, Lange S. Adjusting for multiple testing--when and how? *J Clin Epidemiol*. (2001) 54:343–9. doi: 10.1016/s0895-4356(00)00314-0

21. Wan Azman WN, Omar J, Koon TS, Tuan Ismail TS. Hemolyzed specimens: major challenge for identifying and rejecting specimens in clinical laboratories. *Oman Med J*. (2019) 34:94–8. doi: 10.5001/omj.2019.19

22. Conzemius MG, Evans RB. Caregiver placebo effect for dogs with lameness from osteoarthritis. *J Am Vet Med Assoc*. (2012) 241:1314–9. doi: 10.2460/javma.241.10.1314

23. Conzemius MG, Torres BT, Muir P, Evans R, Krotscheck U, Budsberg S. Best practices for measuring and reporting ground reaction forces in dogs. *Vet Surg*. (2022) 51:385–96. doi: 10.1111/vsu.13772

24. Brown DC, Boston RC, Farrar JT. Use of an activity monitor to detect response to treatment in dogs with osteoarthritis. *J Am Vet Med Assoc*. (2010) 237:66–70. doi: 10.2460/javma.237.1.66

25. Brioschi FA, Di Cesare F, Gioeni D, Rabbogliatti V, Ferrari F, D'Urso ES, et al. Oral Transmucosal Cannabidiol oil formulation as part of a multimodal analgesic regimen: effects on pain relief and quality of life improvement in dogs affected by spontaneous osteoarthritis. *Animals*. (2020) 10:1505. doi: 10.3390/ani10091505

26. Gamble LJ, Boesch JM, Frye CW, Schwark WS, Mann S, Wolfe L, et al. Pharmacokinetics, safety, and clinical efficacy of Cannabidiol treatment in osteoarthritic dogs. *Front Vet Sci*. (2018) 5:165. doi: 10.3389/fvets.2018.00165

27. Klatzkow S, Davis G, Shmalberg J, Gallastegui A, Miscioscia E, Tarricone J, et al. Evaluation of the efficacy of a cannabidiol and cannabidiolic acid rich hemp extract for pain in dogs following a tibial plateau leveling osteotomy. *Front Vet Sci*. (2022) 9:1036056. doi: 10.3389/fvets.2022.1036056

28. Wakshlag JJ, Schwark WS, Deabold KA, Talsma BN, Cital S, Lyubimov A, et al. Pharmacokinetics of Cannabidiol, Cannabidiolic acid, Δ9-tetrahydrocannabinol, Tetrahydrocannabinolic acid and related metabolites in canine serum after dosing with three Oral forms of hemp extract. *Front Vet Sci*. (2020) 7:505. doi: 10.3389/fvets.2020.00505

29. Barter LS, Watson AD, Maddison JE. Owner compliance with short term antimicrobial medication in dogs. *Aust Vet J*. (1996) 74:277–80. doi: 10.1111/j.1751-0813.1996.tb13774.x

30. Bookout W, Dziwenka M, Valm K, Kovacs-Nolan J. Safety study of cannabidiol products in healthy dogs. *Front Vet Sci*. (2024) 11:1349590. doi: 10.3389/fvets.2024.1349590

31. Bradley S, Young S, Bakke AM, Holcombe L, Waller D, Hunt A, et al. Long-term daily feeding of cannabidiol is well-tolerated by healthy dogs. *Front Vet Sci*. (2022) 9:977457. doi: 10.3389/fvets.2022.977457

32. Corsato Alvarenga I, Wilson KM, McGrath S. Tolerability of long-term cannabidiol supplementation to healthy adult dogs. *J Vet Intern Med*. (2024) 38:326–35. doi: 10.1111/jvim.16949

33. McGrath S, Bartner LR, Rao S, Kogan L, Hellyer P. A report of adverse effects associated with the Administration of Cannabidiol in healthy dogs. *Journal of the American Holistic Veterinary Medical Association*. (2018) 52:34–8.

34. Rozental AJ, Weisbeck BG, Corsato Alvarenga I, Gustafson DL, Kusick BR, Rao S, et al. The efficacy and safety of cannabidiol as adjunct treatment for drug-resistant idiopathic epilepsy in 51 dogs: a double-blinded crossover study. *J Vet Intern Med*. (2023) 37:2291–300. doi: 10.1111/jvim.16912

35. Court MH, Mealey KL, Burke NS, Jimenez TP, Zhu Z, Wakshlag JJ. Cannabidiol and cannabidiolic acid: preliminary in vitro evaluation of metabolism and drug-drug interactions involving canine cytochrome P-450, UDP-glucuronosyltransferase, and P-glycoprotein. *J Vet Pharmacol Ther*. (2024) 47:1–13. doi: 10.1111/jvp.13403

36. Jiang R, Yamaori S, Takeda S, Yamamoto I, Watanabe K. Identification of cytochrome P450 enzymes responsible for metabolism of cannabidiol by human liver microsomes. *Life Sci*. (2011) 89:165–70. doi: 10.1016/j.lfs.2011.05.018

37. Mills T, Myers S, Hughes D, Wakshlag J. Tolerability of 2 and 4 mg/kg dosing every 12 hour of a Cannabidiol- and Cannabidiolic acid-rich hemp extract on mixed-breed dogs utilized for teaching in a closed Colony. *Animals*. (2024) 14:1863. doi: 10.3390/ani14131863

38. Charalambous M, Shivapour SK, Brodbelt DC, Volk HA. Antiepileptic drugs' tolerability and safety--a systematic review and meta-analysis of adverse effects in dogs. *BMC Vet Res*. (2016) 12:79. doi: 10.1186/s12917-016-0703-y

39. Selvaraj S, Oh JH, Spanel R, Länger F, Han HY, Lee EH, et al. The pathogenesis of diclofenac induced immunoallergic hepatitis in a canine model of liver injury. *Oncotarget*. (2017) 8:107763–824. doi: 10.18632/oncotarget.21201

40. Corral, MJ, Moyaert, H, Fernandes, T, Escalada, M, Kira, STJ, Walters, RR, et al. A prospective, randomized, blinded, placebo-controlled multisite clinical study of bedinvetmab, a canine monoclonal antibody targeting nerve growth factor, in dogs with osteoarthritis. *Vet Anaesth Analg*, (2021) 48:943–955. doi: 10.1016/j.vaa.2021.08.001

41. Lenth, R, Singmann, H, Love, J, Buerkner, P, and Herve, M. Package Emmeans. R Package version 4.0-3. (2018). Available at: http://cran.r-project.org/package=emmeans

frontiers | Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 17 October 2024
DOI 10.3389/fvets.2024.1431855

OPEN ACCESS

EDITED BY
Heidi Kluess,
Auburn University, United States

REVIEWED BY
Michele N. Maughan,
Excet, United States
Debra Lynn Zoran,
Texas A&M University, United States

*CORRESPONDENCE
Kimberly M. Christie
✉ kmchristie20@gmail.com

RECEIVED 13 May 2024
ACCEPTED 17 September 2024
PUBLISHED 17 October 2024

CITATION
Christie KM, Barnhard JA, Otto CM, Mallikarjun A, Wilson C, Levine D, Tringali AA, Payne CE, Langenbach A and Brunke MW (2024) Interobserver variability of assessing body condition scores and muscle condition scores in a population of 43 active working explosive detection dogs. *Front. Vet. Sci.* 11:1431855.
doi: 10.3389/fvets.2024.1431855

Interobserver variability of assessing body condition scores and muscle condition scores in a population of 43 active working explosive detection dogs

Kimberly M. Christie[1]*, Jennifer A. Barnhard[1,2], Cynthia M. Otto[3], Amritha Mallikarjun[3], Clara Wilson[3], David Levine[4], Ashley A. Tringali[2], Chelsea E. Payne[5], Anke Langenbach[1] and Matthew W. Brunke[6]

[1]Veterinary Surgical Centers, Vienna, VA, United States, [2]Tactical Veterinary Solutions LLC, Cabin John, MD, United States, [3]Penn Vet Working Dog Center, Clinical Sciences and Advanced Medicine, School of Veterinary Medicine, University of Pennsylvania, Philadelphia, PA, United States, [4]Department of Physical Therapy, University of Tennessee at Chattanooga, Chattanooga, TN, United States, [5]U.S. Army Veterinary Corps, Fort Belvoir, VA, United States, [6]Veterinary Referral Associates, Gaithersburg, MD, United States

Objectives: This study aimed to evaluate the agreement between explosive detection dog (EDD) handlers and a team of veterinarians in assessing body condition score (BCS) and muscle condition score (MCS), hypothesizing significant BCS differences between handlers and veterinarians, and no significant MCS differences in healthy active duty EDDs.

Methods: This prospective study analyzed variance and inter-rater intraclass correlation coefficients (ICC) of agreement within BCS and MCS assessments collected from the 43 EDDs by four blinded graders; the EDDs' respective handler and three veterinarians with varying levels of veterinary expertise.

Results: The results of the study showed that 74.4% of the EDD population was graded as ideal BCS (4 or 5 out of 9) by the handlers compared to 67.44% by the members of the veterinary team; however, the graders scored different subsets of individual EDDs as ideal. Normal MCS (3 out of 3) was assessed in 86.05% ($n = 37$) of EDDs by the handlers versus in 70.54% by the veterinary team.

Conclusion: This study highlights the importance of standardized training and guidelines for BCS and MCS assessments in working dogs to improve agreement between all members of the healthcare team.

KEYWORDS

BCS, MCS, detection dog, EDD, handler, working dog, veterinarian

Introduction

Explosive detection dogs (EDDs) play a critical role in detecting and signaling the presence of explosive materials to their handlers (1, 2). Operating in diverse, demanding, and often public-facing environments (e.g., war zones, sports arenas, and transportation hubs), EDDs must maintain peak levels of health and physical fitness to optimally perform their jobs (3, 4). Historically, traditional clinical assessments have relied on body weight to determine and monitor canine health and fitness (5, 6). However, recent attention has shifted to the body condition score (BCS) and, in some cases, muscle condition score (MCS), which offer valuable insights into the balance between body fat and lean muscle composition (4, 7).

Regular assessment and monitoring of BCS, MCS, and body weight (BW) plays a crucial role in detecting, managing, and preventing adverse health effects associated with an imbalance of fat and muscle (8–11). An elevated BCS, for example, has been associated with an array of health issues, including musculoskeletal conditions, endocrine and cardiovascular diseases, neoplastic processes, and a shortened working career and overall life expectancy (4, 12–15). Additionally, overweight and obese dogs, which exhibit higher internal body temperatures and tend to pant as a thermoregulatory response, experience reduced olfaction efficiency because panting prevents them from sniffing simultaneously (16–19). This could have significant consequences given the vital role these dogs serve in public safety.

Objective measurements of BCS and MCS typically involve techniques such as dual-energy X-ray absorptiometry (DEXA), computed tomography (CT), quantitative magnetic resonance (QMR), and ultrasound (8, 10, 20, 21). However, these methods often require costly specialized equipment, specific expertise, or the use of anesthesia, rendering them impractical for working dog handlers or standard veterinary practices (10, 13, 21). Consequently, there is a need for an efficient, affordable, and semi-quantitative method for assessing BCS and MCS. This method should ensure consistent agreement among handlers and veterinary professionals, facilitating effective communication of health and fitness changes to sustain optimal performance.

Scoring of body condition and muscle condition involves both palpation and visual assessment using developed scales to gauge levels of external body fat and lean muscle tissue (8, 22–24). Several validated scoring systems have been utilized to assess BCS including a 5-point scale and a 9-point scale, with the 9-point scale being most common due to its established correlation with DEXA (7, 14, 15, 24, 25). An optimal BCS for dogs on the 9-point scale is 4 to 5, with research suggesting that working dogs may benefit from having a BCS on the lower end of ideal (4, 7, 24). The MCS system, introduced by the World Small Animal Veterinary Association (WSAVA), assesses muscle loss, using a scale ranging from 'normal musculature' to 'marked muscle atrophy' (8). However, the MCS system for dogs currently lacks validation. There is a validated MCS scale for cats which uses a numerical scale ranging from 0 to 3 to indicate the degree of muscle atrophy, with 3 indicating normal musculature although it lacks precise boundaries between categories (9). Despite this limitation, the MCS system is still utilized to subjectively evaluate muscle atrophy resulting from conditions such as sarcopenia or cachexia (9, 10). Both BCS and MCS, when used in combination with a physical examination, can be valuable tools in helping to evaluate a dog's overall physical health and working potential.

While the 9-point BCS scale aims for universal usability (26), there remains a discrepancy in accurately gauging a dog's BCS among individuals with varying levels of veterinary expertise (27–31). Prior research studies found between 44 and 65% of pet and sporting dog owners frequently encounter difficulties accurately gauging their dog's body condition and often underestimate it, especially in cases of overweight dogs (27–31). When evaluating the level of agreement between pet owners and veterinary professionals in determining the BCS of overweight dogs, the analysis shows only a 53% agreement, with 39% of owners rating their overweight dogs as having an ideal BCS (32). Studies evaluating the agreement between individuals assessing MCS have been reported in cats but are sparse in number and have reported agreement between individuals within the veterinary field but not between owners and veterinary professionals (9). There are currently no studies that assess the level of agreement between owners and veterinary professionals on MCS in dogs.

Despite the growing recognition of the importance of BCS and MCS in companion, working, and sporting dog health assessments, there is limited to no research on the agreement between handlers and veterinary professionals in reporting BCS and MCS in working dogs. This study aims to fill this gap by assessing the level of agreement among handlers and a team of veterinarians in grading the BCS and MCS of an active working dog population. We hypothesized that there would be significant differences in reported BCS between handlers and veterinarians, as well as between primary care veterinarians and sports medicine-focused veterinarians. Additionally, we anticipate no significant differences in reported MCS between the graders as it is unlikely to find muscle atrophy in active duty working dogs, leading to minimal variability between grader scores.

Materials and methods

Study design and participants

This prospective study analyzed the level of agreement within BCS and MCS assessments collected from a population of active working EDDs during a routine veterinary visit. BCS and MCS were evaluated by four blinded graders: the EDD's respective handler, an American College of Veterinary Sports Medicine and Rehabilitation (ACVSMR) resident, a diplomate of the ACVSMR (DACVSMR), and a primary care veterinarian of working dogs.

All fifty active federally owned EDDs that were scheduled for their routine veterinary visit were initially enlisted with approval from the canine unit supervisor and handler's informed consent. Eligibility criteria required the EDDs to be healthy, adult (older than 1 year), and actively involved in explosive detection work. Forty-six handlers presented their EDDs for veterinary examination. Two EDDs were excluded for skipping a station and an additional EDD was excluded for completing the stations in the wrong order, resulting in a total of 43 EDDs included as study participants after thorough evaluation.

Animal welfare and ethics

Veterinary Surgical Centers Rehabilitation (VSCR), a private veterinary facility, conducted a Department of Defense (DoD)-supported research study on March 21, 2023. The VSCR veterinary ethics committee reviewed and approved this study (protocol # 230321) on March 14th, 2023, determining it to be veterinary clinical research conducted on client-owned animals and exempt from Institutional Animal Care and Use Committee (IACUC). However, since this study required use of DoD facilities, equipment, and personnel, it also falls under the definition of research, development, test, and evaluation (RDT&E) supported by DoD. IACUC and Component oversight office approval are requirements of DoDI 3216.01 (33). Veterinary research utilizing client owned animals with informed consent is not under any legal requirement to comply with the Animal Welfare Act (34, 35). This study did not have any associated federal funding and therefore is not required to comply with the Public Health Policy (36). The American Veterinary Medical Association recommends that studies utilizing client-owned animals are reviewed by an IACUC or a Veterinary Clinical Studies Committee (VCSS) (37). Although the study did not receive pre-approval from an IACUC or the Component oversight office, informed consent was obtained from relevant officials and handlers and measures were taken to ensure the welfare of all animals involved. BCS and MCS are non-invasive hands-on assessments that do not cause any pain and are conducted routinely to assess fitness in semi-annual physical exams. As requested by the Army Animal Research Compliance and Oversight Office (ARCOO), a waiver to the IACUC and component oversight office approvals required by DoDI 3216.01 for publication of results was granted (Waiver Approval- Study #03212023) on April 14, 2024.

Demographic characteristics

The EDD population, detailed in Table 1, consisted of 7 females (6 altered, 1 intact) and 36 males (4 altered, 32 intact). The median age was 5.3 years (ranging from 1.8 to 11.8 years), with a median weight of 32.2 kg (ranging from 20.2 to 47.9 kg) and a median withers height of 63.4 cm (ranging from 47.5 to 70.4 cm). This study encompassed various breeds, including 12 Belgian Malinois, 11 German Shepherds, 8 German Shorthaired Pointers, 5 Belgian Malinois Mixes, 3 Dutch Shepherds, 3 Labrador Retrievers, and 1 Labrador Retriever Mix, as outlined in Table 2.

Data collection

On March 21st, 2023, 43 EDD teams presented for their routine biannual veterinary visit and completed a rotation of four stations in the following order: Check-in and Handler Survey, Sports Medicine Dynamic Examination, Sports Medicine Complete Physical Examination, and Primary Care Examination. To maintain grader blinding, stations were physically separated (in different rooms).

All graders received laminated reference guides for BCS and MCS at the first of the four stations. At the check-in station (Station 1), each grader was provided with a formal introduction and didactic demonstration by a research and working animal veterinarian (JAB) who served as an instructor, not a grader, for the study. JAB led the graders through the reference guides for both BCS and MCS, which were provided to each handler to follow along as they were read aloud. JAB also helped to orient handlers to the key anatomical landmarks on their dogs for appropriate BCS assessment as well as demonstrated the face analogy using her own face to provide additional clarification for MCS grading.

For BCS assessment, graders received two nine-point BCS visual scales—one tailored for Labrador Retrievers by Nestlé Purina (7) and another for German Shepherds by Royal Canin (38) (see Supplementary Figures 1A,B). BCS scores of 4 or 5 were considered 'ideal,' with scores below 4 classified as 'too thin' and scores over 5 categorized as 'too heavy.'

For MCS assessment, all graders were provided with a modified version of the WSAVA MCS scale (8), which included a visual aid illustrating a human face overlaid with numbers and descriptions relating to the scale (8) (see Supplementary Figure 2). MCS scores of 3 were labeled as 'normal muscle condition,' while scores of 2 indicated mild muscle atrophy, 1 signified 'moderate muscle atrophy,' and 0 indicated 'significant muscle atrophy' (8, 9).

The data collection protocol required each grader to use the provided reference guides while palpating and assigning Body Condition Score (BCS) and Muscle Condition Score (MCS) to the dogs, ensuring consistency across assessments. Handlers received one-on-one instructions with their dogs at each of the four stations. To ensure a collective understanding of the protocol, veterinary graders participated in a single instruction session before the study began. Each grader had access to the reference guides at their station

TABLE 1 Sex, age, body weight, and withers height of EDD participants.

Demographic		Number
Sex	Male neutered	4
	Male intact	32
	Male total	36
	Female spayed	6
	Female intact	1
	Female total	7
Age (years)	Median	5.13
	Minimum	1.81
	Maximum	11.86
Body weight (kg)	Median	32.3
	Minimum	20.2
	Maximum	47.9
Withers height (cm)	Median	63.4
	Minimum	47.5
	Maximum	70.4

Demographic data, including sex and alteration status, as well as median, minimum, and maximum values for age, body weight, and withers height for the EDDs are recorded. These attributes provide a baseline for understanding the study population's physical characteristics.

TABLE 2 Breed of EDD participants.

Breed	Number
Belgian malinois	12
Belgian malinois mix	5
Dutch shepherd	3
German shepherd	11
German shorthaired pointer	8
Labrador retriever	3
Labrador retriever mix	1
Total	43

Summary of the breeds of EDD participants, listing the number of dogs per breed. The data provides insight into breed-specific trends in the study population.

throughout the process. After completing their assessments, graders recorded their responses on anonymized unique identifier (UID) cards, which were collected before the next dog was assessed. No additional tools, methods, or materials beyond the standard protocol were provided.

Station 1: Check-in and handler scoring

Station 1 was overseen by JAB, a research and working animal veterinarian. JAB checked in each EDD team, assigned a UID, confirmed handler consent to participate in the study, provided didactic instructions, and gathered an initial health history for each EDD. A licensed veterinary technician (LVT) distributed four UID cards to each handler, one for use at each station. Handlers then assessed their EDD's body condition score through visual examination and palpation, followed by assigning a muscle condition score based on palpation. Afterward, the LVT weighed each EDD, recording the weight in kilograms. The UID card was collected, and the EDD teams advanced to Station 2.

Station 2: Resident sports medicine exam

Station 2 was led by an ACVSMR resident (KMC). Handlers presented their EDD's UID card to KMC, who conducted a brief physical examination and followed the same protocol as other graders to assess and record the BCS and MCS. Additionally, the withers height was measured and recorded in centimeters (cm) using a standard yardstick (Hyper Tough™, Walmart Distribution Center, Bentonville, Arkansas), from a flat, level ground surface to the highest point of the shoulder blade on either side of the EDD. The corresponding UID card was collected, and the EDD teams proceeded to Station 3.

Station 3: Sports medicine complete physical examination

Station 3 was led by a DACVSMR (MWB). Handlers presented their EDD's UID card to MWB, who performed a comprehensive examination and assessed and recorded BCS and MCS following the same protocol as the other graders. The corresponding UID card was collected, and the EDD teams proceeded to Station 4.

Station 4: Primary care examination

Station 4 was composed of a team of four primary care veterinarians from a practice that routinely provides care for the EDDs. The veterinarians were split into two examination lanes to provide patient care more efficiently. A list of all EDDs requiring care was provided to the veterinarians, and the order of EDD evaluation was based on post-time, with full veterinary care services provided after the BCS and MCS assessments. Although the four veterinarians worked collectively at Station 4, one veterinarian conducted the majority of the assessments, evaluating 26 of the 43 dogs, and was designated as the primary grader for this station. After the UID card was collected from the primary grader at this station, the veterinarians resumed their routine care for each respective EDD.

Statistical analysis

The collected UID cards were processed, and the anonymized data was entered into a Microsoft Excel spreadsheet (Microsoft Corporation. (2018). Microsoft Excel). Excel data was uploaded into R Statistical Software for statistical analysis (v4.3.0; R Core Team 2023) (39). Both the BCS and MCS data were determined to not be normally distributed via Shapiro–Wilk test so Levene's test for homogeneity of variance was used. Levene's test showed that there was no difference in variance across grader, $F(3) = 1.8$, $p = 0.149$. This result met the assumptions for intraclass correlation analysis.

Analysis 1: Examining differences between graders

This analysis assessed whether any of the graders were systematically different from other graders in their determination of canine BCS.

A fully specified linear mixed-effects model was generated using the non-linear mixed effects (nlme) package (40) with BCS as the dependent variable, Grader as the fixed effect, and random intercepts of Dog, Breed, Age, Sex, and Alteration Status. However, this model did not converge, meaning that the statistical algorithm could not find a stable solution to fit the data. This often occurs when a model is too complex or includes too many variables. As a result, a simpler model with random intercepts for Dog, Breed, and Sex was used, which successfully converged and provided a better fit for the data.

This model was compared to reduced models with random intercepts for Dog and Breed only, and Dog only. Akaike Information Criterion (AIC) values were used to compare these models. The AIC is a measure that assesses how well a model fits the data while accounting for model complexity with lower values indicating a better fit. The model with Dog and Breed as random effects had the lowest AIC value, indicating that it was the best-fitting model for the data and was therefore selected for analysis.

The best-fitting linear mixed-effects model used BCS Score as the dependent variable, Grader as the fixed effect, and Dog and Breed as random intercepts to assess the effect of Grader identity on a given BCS score. The model was analyzed using a Type II Wald chi-square test to assess whether Grader as a variable has a significant impact on BCS Score. Post-hoc analyses with a Tukey adjustment comparing individual Graders to each other were done using the estimated marginal means (emmeans) package in R (41).

Analysis 2: Examining correlation between graders

This analysis assessed the extent to which the graders correlate with each other on their BCS ratings of dogs. Within-subject correlations were determined for all graders and pairs of graders using a linear mixed-effects model with BCS as the dependent variable, Grader as the fixed effect, and Dog as a random effect. Confidence intervals (95%) were estimated using a non-parametric bootstrap procedure. This analysis was done using the CorrMixed package in R (42).

Results

Descriptive statistics for BCS

The distribution of BCS ratings, as assigned by each grader, are illustrated in Table 3. The veterinary team and handlers assessed 67.44 and 74.4% of the EDD population, respectively, at an ideal BCS (4 or

TABLE 3 Distribution of EDDs by body condition score (BCS) and grader.

BCS (out of 9)	Handler	Primary care veterinarian	ACVSMR resident	DACVSMR	Veterinary team average (%)	BCS classification
1	0	0	0	0	0.00%	Too thin
2	3	0	0	0	0.00%	Too thin
3	4	2	2	0	3.10%	Too thin
4	18	11	10	12	25.58%	Ideal
5	14	22	12	20	41.86%	Ideal
6	3	7	13	6	20.16%	Too heavy
7	1	1	5	4	7.75%	Too heavy
8	0	0	1	1	1.55%	Too heavy
9	0	0	0	0	0.00%	Too heavy
Total	43	43	43	43	100%	

BCS ratings of the EDDs assigned by handlers and veterinary graders, as well as the percentage of dogs classified as too thin, ideal, or too heavy.

TABLE 4 Contrast values comparing scores for BCS.

Grader 1	Grader 2	Estimate	SE	df	*t*-ratio	*p*-value
Primary care veterinarian	DACVSMR	−0.256	0.149	127	−1.722	0.3165
Primary care veterinarian	ACVSMR resident	−0.349	0.149	127	−2.348	0.0927
Primary care veterinarian	Handler	0.558	0.149	127	3.758	0.0015*
DACVSMR	ACVSMR resident	−0.093	0.149	127	−0.626	0.9235
DACVSMR	Handler	0.814	0.149	127	5.48	<0.001*
ACVSMR resident	Handler	0.907	0.149	127	6.106	<0.001*

The estimate, standard error (SE), degrees of freedom (df), *t*-ratio, and *p*-value are recorded for each pair of graders. The estimate value refers to the difference of marginal means between grader 1 and grader 2, which is the average difference in their BCS scores. The *t*-ratio refers to the difference between sample means divided by the standard error of the difference; if the absolute value of the *t*-ratio scores is high, it will generally result in a higher *p*-value. This analysis highlights the statistical differences in BCS scoring between graders, with a particular focus on the significant differences between handlers and veterinarians. *$p < 0.05$.

5 out of 9); however, the graders scored different subsets of individual EDDs as ideal. Review of the BCS of all graders showed handlers significantly under-scored BCS compared to the three veterinary graders ($p < 0.001$).

All four graders gave the same BCS score for 7 out of the 43 total EDDs (16.28%). For an additional 14 EDDs, three out of the four graders agreed on the BCS. In half of those cases, the grader that did not agree with the other three graders was the handler.

There are 15 dogs out of the total 43 (34.88%) for whom the grader disagreed by more than one BCS point. When the veterinary scores were examined alone, they only differed by more than one point on six dogs (13.95%).

Model 1: Examining differences between graders

This model examined differences between graders in their evaluations of canine BCS. A significant main effect of Grader was observed ($X^2 = 46.92$, $p < 0.001$), such that there were significant differences in graders' scores. Subsequent post-hoc analyses, as detailed in Table 4, revealed that the scores assigned by handlers were significantly lower than those given by veterinarians ($p < 0.001$), while there were no significant differences among the scores assigned by different veterinarians. Figure 1 illustrates the BCS rating of the veterinarians compared to the corresponding handler BCS rating for the same EDD.

Model 2: Examining correlation between graders

This set of models examined the correlation between all graders and then between each pair of graders in their assessments of canine BCS which can be found in Table 5. The estimated correlation coefficient for all graders was found to be 0.62, with a 95% confidence interval ranging from 0.45 to 0.72. When the handlers' scores were excluded, the estimated correlation coefficient for all veterinarians increased to 0.66, with a 95% confidence interval ranging from 0.49 to 0.77.

Variance partition coefficients were calculated to assess the proportion of the variance explained by the random effect variables used in the model; these coefficients result in Intraclass Correlation Coefficient (ICC) values, which measure the degree of agreement or consistency between measurements and were used in our study to assess interrater reliability (43). The ICC for Dog was 0.62 and the ICC for Breed was 0.45, meaning that individual Dog explains 62% of the variance in the data, and Breed explains 45% of the variance. Additionally, the combination of these two random effects explains 69% of the variability in the data, further justifying the use of a

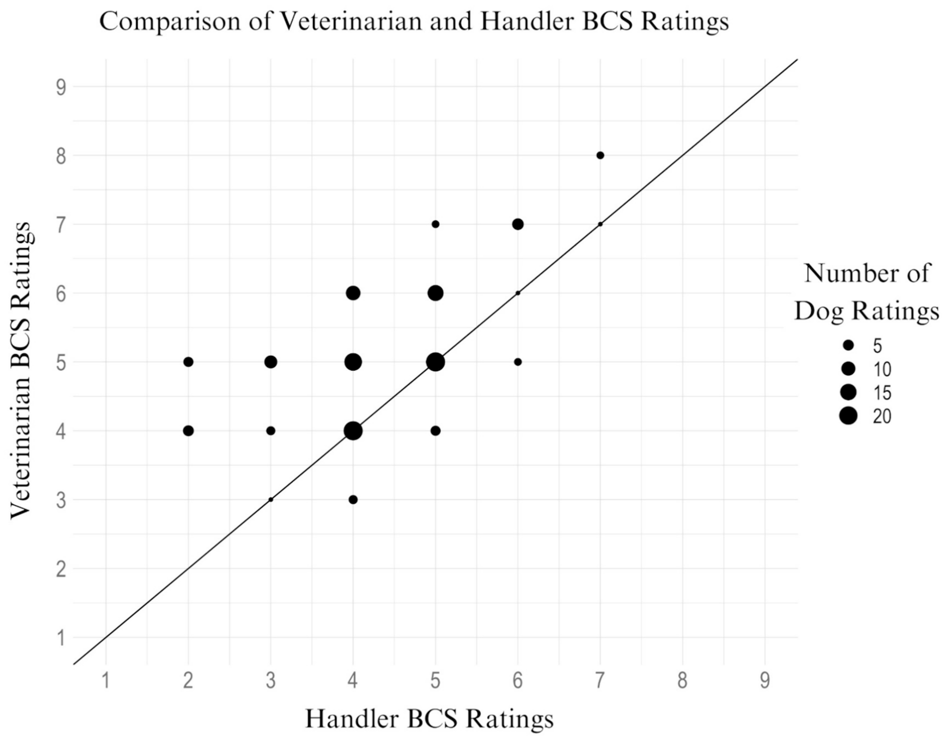

FIGURE 1
Scatter plot of veterinarian BCS rating vs. handler BCS rating for the same EDD. This scatter plot illustrates the relationship between BCS ratings assigned by handlers and veterinarians for the same EDDs. Each bubble represents the number of ratings at a specific BCS score, with bubble sizes ranging from 1 to 20 ratings, with reference example sizes of 5, 10, 15, and 20 shown in the legend. The line of best fit highlights a significant trend ($p < 0.001$) where handlers consistently scored BCS lower than veterinarians, indicating a systematic underscoring by handlers compared to veterinary assessments.

TABLE 5 Correlation coefficients (R^2) for pairs of graders for BCS.

Grader 1	Grader 2	R^2	95% Confidence interval
Primary care veterinarian	DACVSMR	0.52	[0.18, 0.69]
Primary care veterinarian	ACVSMR resident	0.53	[0.28, 0.73]
Primary care veterinarian	Handler	0.34	[0.05, 0.55]
DACVSMR	ACVSMR resident	0.88	[0.79, 0.93]
DACVSMR	Handler	0.68	[0.46, 0.82]
ACVSMR resident	Handler	0.65	[0.45, 0.78]

The level of agreement between pairs of graders is demonstrated by the correlation coefficients (represented by R^2). The higher the correlation coefficient on a scale of 0 to 1, the stronger the association. This table illustrates the degree of consistency in BCS evaluations among different graders.

multilevel model given the high level of variance explained by these variables.

Descriptive statistics for MCS

The MCS given to the EDD population by each grader is presented in Table 6. The handlers graded 86.05% (n=37) of EDDs as having normal MCS (3 out of 3) versus 70.54% by the veterinary team. Mild muscle atrophy (MCS 2 out of 3) was assessed in 13.95% (n=6) of EDDs by the handlers versus an average of 29.46% by the veterinary team. No EDDs were evaluated to have moderate muscle atrophy (MCS 1 out of 3) or marked muscle atrophy (MCS 0 out of 3) by any grader.

Discussion

To the authors' knowledge, this is the first study to assess working canine handlers' evaluations of their dogs' BCS and MCS and to compare them to veterinarians. The results of our study demonstrated there was no significant difference amongst veterinary professionals in BCS scoring, regardless of their level of expertise. However, the results also revealed a significant disparity between handlers and veterinary graders in which handlers scored their canine partners' BCS significantly lower than veterinary graders (Table 4). This underscoring of BCS is consistent with previous research on owner assessment of their own dogs' BCS (27–32). Despite handlers' specialized training in working with their canine partners, variations in expertise or training related to BCS assessment may contribute to the underestimation of BCS scoring by handlers compared to veterinary graders. Previous research by Gille et al. (44) highlighted the challenges individuals face in assigning accurate BCS if unfamiliar with BCS scales. While information regarding handlers' experiences and familiarity with BCS scales was unavailable during data collection, it is possible handlers lacked prior exposure and/or experience to the scales used

TABLE 6 Distribution of EDDs by muscle condition score (MCS) and grader.

MCS (out of 3)	Handler *n* (%)	Primary care veterinarian *n* (%)	ACVSMR resident *n* (%)	DACVSMR *n* (%)	Veterinary team average (%)	MCS classification
0	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0.00%	Marked muscle atrophy
1	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0.00%	Moderate muscle atrophy
2	6 (13.95%)	5 (11.63%)	11 (25.48%)	22 (48.84%)	29.46%	Mild muscle atrophy
3	37 (86.05%)	38 (88.37%)	32 (74.42%)	21 (51.16%)	70.54%	Normal musculature
Total	43	43	43	43	100%	

The distribution of MCS ratings assigned by both handlers and veterinary graders, as well as the percentages for each MCS category (normal muscle condition, mild muscle atrophy, etc.) are recorded. The table highlights the differences between handler and veterinary assessments, illustrating any discrepancies in muscle condition scoring. These comparisons provide insight into the level of consistency between handlers' and veterinarians' evaluations of muscle condition in working dogs.

in this study, affecting their ability to assign BCS scores accurately or in agreement with veterinary graders.

This study also evaluated the level of agreement between graders in the assessment of BCS as illustrated in Table 5. The agreement in BCS assessment between all four graders was 0.62, which indicated a moderate agreement. However, the highest level of agreement, at 0.88 (Table 5), occurred between the ACVSMR resident and the DACVSMR, indicating good agreement. This suggests a stronger consensus between these two graders than among all four graders collectively. The higher agreement noted between the ACVSMR resident and the DACVSMR could be explained by similar training in BCS assessment, along with the additional emphasis on BCS within the specialty of canine sports medicine.

Despite the moderate to good level of agreement on BCS among the graders in our study, the handlers consistently underscored the BCS of their respective canine partners compared to the three veterinary graders. This discrepancy may suggest that veterinarians have an increased familiarity with BCS assessment charts and experience evaluating fit, healthy dog populations, causing them to score BCS more similarly. The three veterinary professionals evaluated the EDDs without familiarity bias, as they had no prior attachment to the dogs during data collection. This lack of familiarity bias likely contributed to the observed agreement among the veterinary graders in BCS evaluation. Furthermore, veterinarians specializing in canine sports medicine may have increased utilization of BCS assessment practices in working dogs, potentially resulting in better agreement among this group. While proficiency in BCS scales is crucial for identifying potential health issues in working dogs, including EDDs, further research is needed to assess the impact of additional training on inter-rater agreement.

Our study enrolled only healthy, active-duty EDDs, with three out of four graders assessing 32–38 dogs (74.42–88.37%) as having normal muscle condition. In our study, the DACVSMR assessed 48.84% ($n = 22$) of the EDDs to have mild muscle atrophy. This could be due to the DACVSMR's extensive experience in utilizing MCS in the assessment of working dogs. The current unipolar MCS scale is designed for disease detection (8, 10, 20, 24, 45) and therefore limited in identifying positive muscle development. A bipolar MCS scale which encompasses not only the absence of muscle atrophy, but also incorporates varying degrees of muscle development, could be considered. Ramos et al. (4) proposed such a scale, grading MCS out of a total of 5. In their framework, an MCS of 4 indicates toned musculature, ideal for athletic dogs (sporting dogs and most working dogs), and an MCS of 5 signifies hypertrophic muscle or 'double muscling,' which could be suitable for certain specialized working dogs or represent a pathologic change. A bipolar MCS scale would allow for a more complete assessment of a canine's muscular health and bring it into further alignment with the BCS framework.

While our study design prevented leakage of graders' assessments to the other graders during the study, handlers' prior experiences were not investigated in this study, but may have influenced handler responses. Handlers are frequently exposed to public, trainer, and veterinary comments on the body condition of their dogs. Previous comments or assessments, particularly if associated with negative societal connotations, may have contributed to a conformity bias and influenced how the handlers evaluated their EDDs in our study.

There are limitations to our study. One limitation is the potential bias introduced during data collection. As stated in the Materials and Methods, all graders were given laminated reference guides of BCS and MCS (see Supplementary Figures 1A,B) which included descriptive language and colors. The BCS scales used include words such as 'obese,' 'overweight,' 'too heavy,' and 'too thin' with red and yellow coloration. Such words can carry more negative connotations, as demonstrated in a 2013 study by Puhl et al. (46). Less experienced graders may have been influenced by these terms, potentially skewing their assessments. Furthermore, the use of specific colors, such as green for an 'ideal' BCS or the addition of a lighter background color to highlight the 'ideal' scores on a BCS chart, may have encouraged graders to select certain scores for an EDD, regardless of their initial evaluation of the dog's body condition. Conversely, red and yellow or darker background colors for 'obese,' 'overweight,' and 'too heavy' may have encouraged graders to avoid selecting certain scores. The use of less common terms, like 'atrophy' instead of 'loss' on the MCS chart may have biased graders less familiar with these terms, leading to unintentional misinterpretation rather than evaluating the amount of lean muscle tissue accurately. To mitigate potential bias, future charts could be printed in black and white, distributed without descriptive wording, or be modified to include more common wording allowing graders to assess the dogs solely based on visual evaluation and palpation as intended.

It is also recognized that handlers are biased toward their own dog's performance and are more critical of other dogs (47). In our study, handlers graded the highest percentage of dogs as ideal BCS compared to the veterinary team (74.4 and 67.44%, respectively). This positive bias toward a handler's own dog may have contributed to our result and future studies could test this by having a handler or handlers assess a group of working dogs that excluded their canine partner to determine if the results would differ from those in this study.

While our study focused on assessing the level of agreement for BCS and MCS within a healthy, active-duty EDD population, further investigations into diverse working dog populations are necessary to assess the relevance of our findings. Examining other working dog cohorts could uncover additional variations in inter-rater agreement, especially considering the potential heterogeneity in these populations. These variations may stem from differences in breeds, tasks, environmental conditions, and overall health status among the different populations of working dogs. Furthermore, expanding the study to include additional graders, such as trainers familiar with the specific tasks and physical requirements of working dogs, or employing different handler/canine pairings, could help us to understand the influence of expertise or specialized training in BCS and MCS assessment. By incorporating perspectives from various personnel involved in the care and training of working dogs, we can gain a more comprehensive understanding of the factors influencing inter-rater agreement and improve the accuracy and reliability of BCS and MCS evaluations across diverse working dog populations.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The animal studies were approved by the Veterinary Surgical Centers Rehabilitation Veterinary Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the handlers for the participation of their animals in this study.

Author contributions

KMC: Conceptualization, Investigation, Methodology, Writing – original draft. JAB: Data curation, Writing – review & editing. CMO: Conceptualization, Methodology, Writing – review & editing. AM: Formal analysis, Writing – review & editing. CW: Writing – review & editing. DL: Data curation, Writing – review & editing. AAT: Writing – review & editing. CEP: Writing – review & editing, Investigation. AL: Funding acquisition, Writing – review & editing. MWB: Conceptualization, Methodology, Supervision, Writing – review & editing, Investigation, Project administration.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. The monetary costs for submission were paid for by Veterinary Surgical Centers Rehabilitation's ACVSMR resident research fund.

Acknowledgments

The authors would like to express our gratitude to all the handlers, dogs, and veterinary staff for their time and participation. Special thanks to Leslie Truesdale, LVT for her help with organizing and collecting data during the site visit.

Conflict of interest

JAB and AAT were employed by Tactical Veterinary Solutions LLC.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

Author disclaimer

The views and information presented are those of the authors and do not represent the official policy or position of their affiliated institutions, the Department of Defense, or the U.S. Government.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2024.1431855/full#supplementary-material

References

1. MacLean EL, Hare B. Enhanced selection of assistance and explosive detection dogs using cognitive measures. *Front Vet Sci*. (2018) 5:408876. doi: 10.3389/fvets.2018.00236

2. Lazarowski L, Waggoner LP, Krichbaum S, Singletary M, Haney P, Rogers B, et al. Selecting dogs for explosives detection: behavioral characteristics. *Front Vet Sci*. (2020) 7:597. doi: 10.3389/fvets.2020.00597

3. Otto CM, Darling T, Murphy L, Ng Z, Pierce B, Singletary M, et al. 2021 AAHA working, assistance, and therapy dog guidelines. *J Am Anim Hosp Assoc*. (2021) 57:253–77. doi: 10.5326/JAAHA-MS-7250

4. Ramos MT, Farr BD, Otto CM. Sports medicine and rehabilitation in working dogs. *Vet Clin North Am Small Anim Practice*. (2021) 51:859–76. doi: 10.1016/j.cvsm.2021.04.005

5. Salt C, Morris PJ, German AJ, Wilson D, Lund EM, Cole TJ, et al. Growth standard charts for monitoring bodyweight in dogs of different sizes. *PLoS One*. (2017) 12:e0182064. doi: 10.1371/journal.pone.0182064

6. German AJ, Morgan LE. How often do veterinarians assess the bodyweight and body condition of dogs? *Vet Rec*. (2008) 163:503–5. doi: 10.1136/vr.163.17.503

7. Laflamme DP. Development and validation of a body condition score system for dogs. *Canine Practice*. (1997) 22:10–5.

8. WSAVA Nutritional Assessment Guidelines Task Force MembersFreeman L, Becvarova I, Cave N, MacKay C, Nguyen P, et al. WSAVA Nutritional Assessment Guidelines. J Small Anim Pract. (2011) 52:385–96. doi: 10.1111/j.1748-5827.2011.01079.x

9. Michel KE, Anderson W, Cupp C, Laflamme DP. Correlation of a feline muscle mass score with body composition determined by dual-energy X-ray absorptiometry. *Br J Nutr*. (2011) 106:S57–9. doi: 10.1017/S000711451100050X

10. Freeman LM, Sutherland-Smith J, Prantil LR, Sato AF, Rush JE, Barton BA. Quantitative assessment of muscle in dogs using a vertebral epaxial muscle score. Can J Vet Res (2017): 1;81:255–260

11. Shepherd M. Canine and feline obesity management. *Vet Clin*. (2021) 51:653–67. doi: 10.1016/j.cvsm.2021.01.005

12. Kealy RD, Lawler DF, Ballam JM, Mantz SL, Biery DN, Greeley EH, et al. Effects of diet restriction on life span and age-related changes in dogs. *J Am Vet Med Assoc*. (2002) 220:1315–20. doi: 10.2460/javma.2002.220.1315

13. German AJ. The growing problem of obesity in dogs and cats. *J Nutr*. (2006) 136:1940S–6S. doi: 10.1093/jn/136.7.1940S

14. Lund EM, Armstrong PJ, Kirk CA, Klausner JS. Prevalence and risk factors for obesity in adult dogs from private US veterinary practices. *Int J Appl Res Vet Med*. (2006) 4:177.

15. German AJ, Ryan VH, German A, Wood IS, Trayhurn P. Obesity, its associated disorders and the role of inflammatory adipokines in companion animals. *Vet J*. (2010) 185:4–9. doi: 10.1016/j.tvjl.2010.04.004

16. Gazit I, Terkel J. Domination of olfaction over vision in explosives detection by dogs. *Appl Anim Behav Sci*. (2003) 82:65–73. doi: 10.1016/S0168-1591(03)00051-0

17. Manens J, Ricci R, Damoiseaux C, Gault S, Contiero B, Diez M, et al. Effect of body weight loss on cardiopulmonary function assessed by 6-minute walk test and arterial blood gas analysis in obese dogs. *J Vet Intern Med*. (2014) 28:371–8. doi: 10.1111/jvim.12260

18. Otto CM, Hare E, Nord JL, Palermo SM, Kelsey KM, Darling TA, et al. Evaluation of three hydration strategies in detection dogs working in a hot environment. *Front Vet Sci*. (2017) 4:174. doi: 10.3389/fvets.2017.00174

19. Aviles-Rosa E, Schultz J, Maughan MN, Gadberry JD, DiPasquale DM, Farr B, et al. A canine model to evaluate the effect of exercise intensity and duration on olfactory detection limits: the running nose. *Front Allergy*. (2024) 5:1367669. doi: 10.3389/falgy.2024.1367669

20. Freeman LM, Michel KE, Zanghi BM, Vester Boler BM, Fages J. Evaluation of the use of muscle condition score and ultrasonographic measurements for assessment of muscle mass in dogs. *Am J Vet Res*. (2019) 80:595–600. doi: 10.2460/ajvr.80.6.595

21. Santarossa A, Parr JM, Verbrugghe A. The importance of assessing body composition of dogs and cats and methods available for use in clinical practice. *J Am Vet Med Assoc*. (2017) 251:521–9. doi: 10.2460/javma.251.5.521

22. Burkholder WF. Use of body condition scores in clinical assessment of the provision of optimal nutrition. *J Am Vet Med Assoc*. (2000) 217:650–4. doi: 10.2460/javma.2000.217.650

23. German AJ, Holden SL, Moxham GL, Holmes KL, Hackett RM, Rawlings JM. A simple, reliable tool for owners to assess the body condition of their dog or cat. *J Nutr*. (2006) 136:2031S–3S. doi: 10.1093/jn/136.7.2031S

24. Baldwin KE, Bartges JW, Buffington T, Freeman LM, Grabow M, Legred J, et al. AAHA nutritional assessment guidelines for dogs and cats. *J Am Anim Hosp Assoc*. (2010) 46:285–96. doi: 10.5326/0460285

25. Mawby DI, Bartges JW, D'Avignon A, Laflamme DP, Moyers TD, Cottrell T. Comparison of various methods for estimating body fat in dogs. *J Am Anim Hosp Assoc*. (2004) 40:109–14. doi: 10.5326/0400109

26. Chun JL, Bang HT, Ji SY, Jeong JY, Kim M, Kim B, et al. A simple method to evaluate body condition score to maintain the optimal body weight in dogs. *J Anim Sci Technol*. (2019) 61:366–70. doi: 10.5187/jast.2019.61.6.366

27. Eastland-Jones RC, German AJ, Holden SL, Biourge V, Pickavance LC. Owner misperception of canine body condition persists despite use of a body condition score chart. *J Nutr Sci*. (2014) 3:e45. doi: 10.1017/jns.2014.25

28. Teixeira FG, Queiroz MR, Oba PM, Olivindo RFG, Ernandes MC, Duarte CN, et al. Brazilian owners perception of the body condition score of dogs and cats. *BMC Vet Res*. (2020) 16:463. doi: 10.1186/s12917-020-02679-8

29. Courcier EA, Mellor DJ, Thomson RM, Yam PS. A cross sectional study of the prevalence and risk factors for owner misperception of canine body shape in first opinion practice in Glasgow. *Prev Vet Med*. (2011) 102:66–74. doi: 10.1016/j.prevetmed.2011.06.010

30. Kluess HA, Jones R, Lee-Fowler TM. Perceptions of body condition, diet and exercise by sports dog owners and pet dog owners. *Animals*. (2021) 11:1752. doi: 10.3390/ani11061752

31. Yam PS, Naughton G, Butowski CF, Root A. Inaccurate assessment of canine body condition score, bodyweight, and pet food labels: a potential cause of inaccurate feeding. *Vet Sci*. (2017) 4:30. doi: 10.3390/vetsci4020030

32. White GJ, Hobson-West P, Cobb KM, Craigon J, Hammond R, Millar K. Canine obesity: is there a difference between veterinarian and owner perception? *J Small Anim Pract*. (2011) 52:622–6. doi: 10.1111/j.1748-5827.2011.01138.x

33. Department of Defense (DoD). DoD Instruction (DoDI) 3216.01 Use of animals in dod conducted and supported research and training [Internet]. Office of the Under Secretary of Defense for Research and Engineering. (2019).

34. United States Code. Title 7 (Agriculture), Chapter 54 (Transportation, Sale, and Handling of Certain Animals), Sections 2131–2159. Office of the Law Revision Counsel, U.S. House of Representatives. (1985). Available at: https://uscode.house.gov

35. Code of Federal Regulations. Title 9 (Animals and Animal Products), Chapter 1 (Animal and Plant Health Inspection Service, Department of Agriculture), Subchapter A (Animal Welfare), Parts 1-4. U.S Government Publishing Office. (2023).

36. National Institutes of Health, Office of Laboratory Animal Welfare. Public Health Service Policy on Humane Care and Use of Laboratory Animals. U.S. Department of Health and Human Services. (2015). Available at: https://olaw.nih.gov

37. American Veterinary Medical Association Policy. Establishment and use of veterinary clinical studies committees. American Veterinary Medical Association, Schaumburg, IL. Available at: https://www.avma.org/resources-tools/avma-policies/establishment-and-use-veterinary-clinical-studies-committees (Accessed November 3, 2023).

38. Body Condition Score Charts Cat and Small Dog. (2013). Available at: https://www.royalcanin.co.uk/wp-content/uploads/2017/02/BCS-chart-03.12.13.pdf (Accessed April 16, 2023).

39. R Core Team. R: A language and environment for statistical Computing. Vienna, Austria: R Foundation for Statistical Computing (2023).

40. Pinheiro J., Bates D.R Core Team. (2023). *nlme: Linear and nonlinear mixed effects models* (R package version 3.1–163). Available at: https://CRAN.R-project.org/package=nlme

41. Lenth R. (2024). *emmeans: Estimated marginal means, aka least-squares means* (R package version 1.10.2). Available at: https://CRAN.R-project.org/package=emmeans

42. Van der Elst W., Molenberghs G., Hilgers D., Heussen N. (2022). *CorrMixed: Estimate correlations between repeatedly measured endpoints (e.g., reliability) based on linear mixed-effects models* (R package version 1.1). Available at: https://CRAN.R-project.org/package=CorrMixed

43. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med*. (2016) 15:155–63. doi: 10.1016/j.jcm.2016.02.012

44. Gille S, Fischer H, Lindåse S, Palmqvist L, Lärka J, Wolf S, et al. Dog owners' perceptions of dog body composition and effect of standardized education for dog owners on body condition assessment of their own dogs. *Vet Sci*. (2023) 10:447. doi: 10.3390/vetsci10070447

45. Freeman LM. Cachexia and sarcopenia: emerging syndromes of importance in dogs and cats. *J Vet Intern Med*. (2012) 26:3–17. doi: 10.1111/j.1939-1676.2011.00838.x

46. Puhl R, Peterson JL, Luedicke J. Motivating or stigmatizing? Public perceptions of weight-related language used by health providers. *Int J Obes*. (2013) 37:612–9. doi: 10.1038/ijo.2012.110

47. Clark CC, Sibbald NJ, Rooney NJ. Search dog handlers show positive bias when scoring their own dog's performance. *Front Vet Sci*. (2020) 7:612. doi: 10.3389/fvets.2020.00612

frontiers | Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 28 October 2024
DOI 10.3389/fvets.2024.1466405

Check for updates

OPEN ACCESS

EDITED BY
Denis J. Marcellin-Little,
University of California, Davis, United States

REVIEWED BY
Matthew Warren Brunke,
Veterinary Referral Associates, United States
Kelli Mossine,
Mossine Veterinary Neurology Services LLC,
United States

*CORRESPONDENCE
Jennifer Repac
✉ jrepac@ufl.edu

RECEIVED 17 July 2024
ACCEPTED 30 August 2024
PUBLISHED 28 October 2024

CITATION
Narum M, Miscioscia E and Repac J (2024) Caretaker-reported quality of life, functionality, and complications associated with assistive mobility cart use in companion animals.
Front. Vet. Sci. 11:1466405.
doi: 10.3389/fvets.2024.1466405

Caretaker-reported quality of life, functionality, and complications associated with assistive mobility cart use in companion animals

Melissa Narum, Erin Miscioscia and Jennifer Repac*

Department of Comparative, Diagnostic, and Population Medicine, College of Veterinary Medicine, University of Florida, Gainesville, FL, United States

Objective: To evaluate the impact of assistive mobility carts on companion animals and caretakers' quality of life by investigating factors pertaining to caretaker satisfaction, the ability to perform daily tasks, and complication rates.

Materials and methods: A 23-question survey was distributed to caretakers of animals using carts to evaluate the animal and caretakers' quality of life, acceptance, ability to complete functional tasks, and complications. Data from canine, feline, and rabbit responses were analyzed separately.

Results: Dogs and cats had improved quality of life in 62 and 57% of responses and 61 and 60% for their caretakers, respectively. There was no improvement in the quality of life of rabbits or their caretakers. Regarding the complication rate, 64% were reported to have at least one complication associated with cart use, 53% of which were wounds. Across all species, there was a reported improvement in ability to perform daily tasks and activities.

Conclusions and clinical relevance: Caretakers reported that assistive mobility carts improve both companion animals' and caretakers' quality of life, despite high prevalence of complications, including wounds. Future studies exploring specific disease conditions and long-term outcomes will be useful for guiding clinical recommendations.

KEYWORDS

cart, wheelchair, mobility, assistive device, veterinary rehabilitation, spinal cord injury

1 Introduction

Assistive mobility devices are designed to improve quality of life by providing independent mobility to the user. In human medicine, assistive devices such as wheelchairs, crutches, and walking canes can be used to aid mobility (1–3). Similarly, assistive mobility devices can be used for companion animals with a range of mobility disorders (4–7). In veterinary medicine, studies have explored the application, acceptance rate, and complications of prosthetic and orthotic assistive mobility devices (8–10). Independent mobility will impact both the animal and caretaker quality of life and can impact the strength of the human-animal bond (11–14).

Veterinary assistive mobility carts, sometimes called "wheelchairs" or "carts," are generally composed of a saddle or harness attached to a rigid structure supported by 2–4 wheels, depending on individual needs. Numerous brands of veterinary carts offer customized and standard options designed to support animals with mobility disorders. The most common indications for cart use in companion animals are neurological or orthopedic diseases. Spinal cord injury or degenerative conditions are the most common neurological causes leading to impairment or inability to ambulate independently (14, 15). These can include specific conditions, such as intervertebral disc disease and non-compressive myelopathies (such as fibrocartilaginous embolism or acute non-compressive nucleus pulposus extrusion), or degenerative diseases, such as degenerative myelopathy (6, 16). Orthopedic conditions such as joint disease or amputations can also impair an animal's independent mobility (17, 18).

To the authors' knowledge, no studies have examined the use of assistive mobility carts in veterinary medicine. Given the growing prevalence of these products, there is a need for research to guide clinical recommendations. The objective of this caretaker survey study is to evaluate how assistive mobility carts impact the quality of life of both companion animals and their caretakers. The secondary aim was to report other factors that may impact overall satisfaction, including cart type and complication rate. We hypothesized that the majority of animals using carts, and their caretakers, will experience improved quality of life.

2 Materials and methods

A 23-question online survey was developed to obtain information about assistive mobility cart use, acceptance, and impact on quality of life for both animals and caretakers. This survey was active from 2/1/23 to 2/15/23. The survey was developed on the Qualtrics platform (Qualtrics, Provo, UT) for distribution purposes. The collected information included species, age, cart brand, time to acceptance and daily use, complications and wounds, ability to perform basic tasks/activities, perceived animal and caretaker quality of life and whether use would be recommended to another caretaker. The information was caretaker-reported and anonymized. The survey was designed as a single assessment. The styles of questions included multiple choice, yes/no and select all that apply. There were a couple questions that included an option for a fill-in-the blank response. The survey questions are listed in Supplementary Table 1. The survey was distributed with an introductory paragraph to explain the goals of the survey and reach the appropriate audience. Participation in the survey was intended to be anonymous with the primary requirement being ownership of an animal that previously used or is currently using an assistive mobility cart. The summaries used prior to distribution and at the time of distribution are available in Supplementary Table 1.

2.1 Survey distribution

The survey was emailed to the caretakers of companion animals utilizing carts within the University of Florida College of Veterinary Medicine Integrative and Mobility Medicine Service and the American Association of Rehabilitation Veterinarians (AARV), Academy of Physical Rehabilitation Veterinary Technicians (APRVT), and Veterinary Sports Medicine and Rehabilitation (VSMR) listservs. The survey link was also posted on Facebook groups related to canine neurological or orthopedic diseases, the VSMR newsletter, and the VSMR resident Facebook page.

Responses from canine, feline, and rabbit use of carts were analyzed in this study. Responses in a different language or responses flagged as a "bot" response by the Qualtrics security screening were excluded. Responses for which the species was listed as "other" and written text responses were not provided were also excluded. If a specific dog breed was listed for those who selected "other," these were reorganized appropriately to be counted as "dog" responses. Age was collected in years and grouped into 4 categories: "<1 years old," "1–6 years old," ">6 years old" and "deceased." These age ranges were derived from the AAHA Canine Life Stage Guidelines (19).

2.2 Statistics

Survey responses were summarized as counts and binomial proportions as appropriate. For individual proportions, a chi square test of equal proportions between (i.e., positive/negative, yes/no) responses was used and binomial 95% confidence intervals are given. For comparison of differences in proportions between multiple groups a logistic linear model was used. When global tests of grouped differences were found to be significant, *post hoc* group comparisons were made using Tukey's multiple comparisons procedure with letter groupings and overall significance based on alpha level 0.05.

3 Results

A total of 1,778 survey responses were received. Following the application of exclusion criteria, 1,221 survey responses were available for review. There were a total of 954 responses for dogs, 219 for cats, and 46 for rabbits. A portion of responses were incomplete with the completed portions being retained for analysis.

Approximately 42% of all responses listed a neurological cause and 47% listed an orthopedic cause as the reason for cart use. The remaining responses cited either a combination of neurological and orthopedic diseases, unspecified congenital disease, or unknown reasons. Eleven commercial brands of assistive mobility carts were reported to be used in addition to homemade carts. Table 1 displays the number of

TABLE 1 Distribution of responses for the 6 most common brands of assistive mobility cart (see text footnotes 1–6).

Brand of cart	Total number responses
Brand 1	248
Brand 2	363
Brand 3	195
Brand 4	172
Brand 5	82
Brand 6	79

TABLE 2 Impact of assistive mobility cart use on animal and caretaker quality of life (QOL) by species.

	Species	Positive responses	Total responses	*p* value
Animal QOL	All species	715 (60%)	1,195	<0.001
	Dog	571 (62%)	922	<0.001
	Cat	124 (57%)	217	0.035
	Rabbit	16 (35%)	46	0.038
Caretaker QOL	All species	713 (60%)	1,192	<0.001
	Dog	561 (61%)	920	<0.001
	Cat	130 (60%)	216	0.0028
	Rabbit	18 (39%)	46	0.14

TABLE 3 Cart type impact (quad, front wheel, hind wheel) on animal and caretaker quality of life (QOL) for each species.

	Species	Quad (positive/total)	Front wheel (positive/total)	Hind wheel (positive/total)	*p* value
Animal QOL	Dog	140/260 (54%)[b]	105/223 (47%)[b]	323/435 (74%)[a]	<0.001
	Cat	59/88 (67%)[a]	41/89 (46%)[b]	24/38 (63%)[ab]	0.014
	Rabbit	3/11 (27%)	7/21 (33%)	5/13 (39%)	0.85
Caretaker QOL	Dog	143/260 (55%)[b]	111/223 (50%)[b]	304/433 (70%)[a]	<0.001
	Cat	59/87 (68%)[a]	42/89 (47%)[b]	28/38 (63%)[a]	0.0035
	Rabbit	6/11 (55%)	7/21 (33%)	5/13 (39%)	0.51

Percentages with different superscripts (eg. ab) indicate statistical differences between the columns. Rabbit responses were not included in the Tukey–Kramer least square means comparison.

responses for the six most common brands.[1, 2, 3, 4, 5, 6] For dogs, there was an inverse relationship between size and ease of cart loading. As size increased, placement became more difficult ($p < 0.001$).

3.1 Quality of life

For dogs and cats, there was a significant improvement in the quality of life of both animals and caretakers. Dogs were reported to have an improved quality of life in 62% of responses ($p < 0.001$) for animal quality of life and 61% for caretaker quality of life. Cats were reported to have improved quality of life in 57% of responses ($p = 0.035$) and 60% for their caretakers ($p = 0.0028$). For rabbits, there was not a majority response to improvement in quality of life for either the animal (35%, $p = 0.04$) or the caretaker (39%, $p = 0.14$). The specific values are listed in Table 2.

The quality of life responses related to the type of cart and species of animals and caretakers are detailed in Table 3. For dogs and cats, there was a statistically significant improvement in quality of life for both the animal and caretaker when using both quad carts (4 wheels) and hind wheel carts, but not front wheel carts. For dogs, use of hind wheel carts had a statistically significant improvement when compared to quad or front wheel carts for animal quality of life. In cats, quad carts had a statistically significant improvement in animal quality of life when compared to front wheel carts. There was no statistical difference between hind wheel carts and either quad or front wheel carts for cats. When considering caretaker quality of life, there was a statistically significant improvement in quality of life for both quad carts and

1 Walkin' Pets, 105 Route 101A, Suite 18, Amherst, NH 03031.

2 Eddie's Wheels, Eddie's Wheels Custom Dog Wheelchairs 140 State Street, Shelburne Falls, MA 01370.

3 K9 Carts, Paw Prosper Company, 2,851 Placida Rd., Units A & B Englewood, FL 34224.

4 Doggon' Wheels, Doggon' Wheels LLC, 1032 Irving St #501, San Francisco, CA 94116.

5 Ruff Rollin', 1,505 14th Street SW, Suite #103, Great Falls MT 59404.

6 Best Friend Mobility, 279 Hwy 57S STE4, Little River, SC 29566, USA.

TABLE 4 Complication rates associated with assistive mobility cart use by species.

Species	Responses reporting complications	Total responses	Complication rate (%), [CI 95%]	*p* value
All species	782	1,230	64% [61, 66%]	<0.001
Dog	575	954	60% [57, 63%]	<0.001
Cat	166	219	76% [70, 81%]	<0.001
Rabbit	33	46	72% [59, 85%]	0.0032

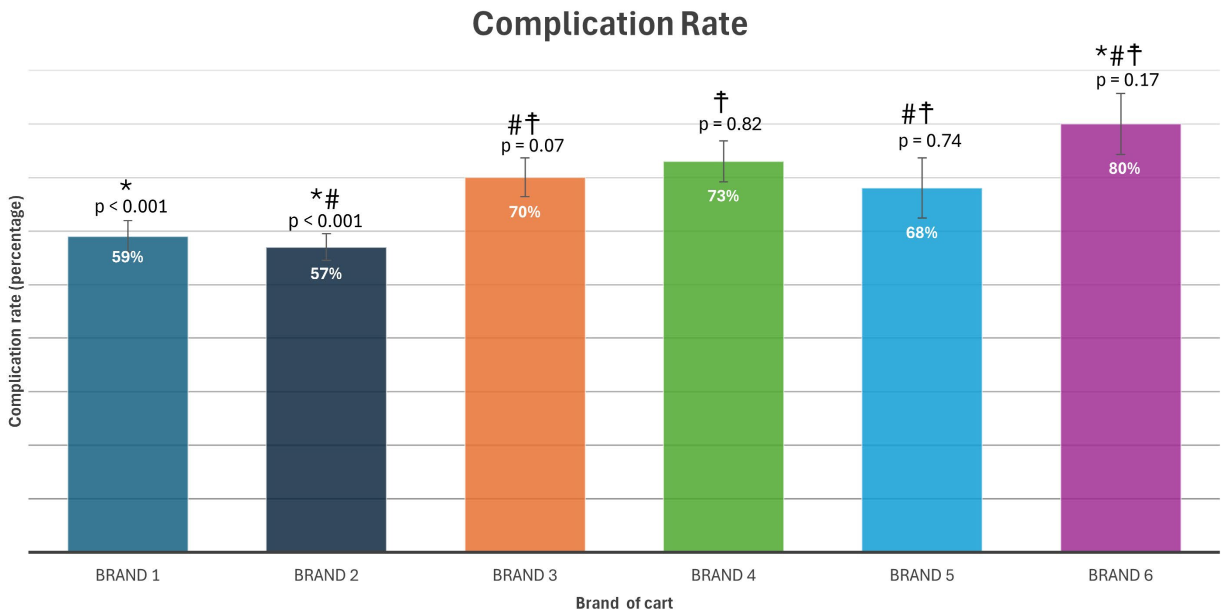

FIGURE 1
Complication rate for six most common brands (see text footnotes 1–6) with Tukey grouping of significance. Percentages with different symbols are statistically different between brands ($p < 0.05$).

hind wheel carts when compared to front wheel carts in both dogs and cats. There was no statistical difference between quad carts and hind wheel carts for either of these species.

There was no difference in the reported quality of life between cart types in rabbits ($p = 0.51$). There was no significant relationship between the duration of cart use per day and quality of life for animals or caretakers across all species. There was a direct relationship between animal size and both positive animal and caretaker quality of life ($p < 0.001$).

Across all species, the majority of caretakers (79%) were likely to recommend cart use to others. Caretakers who reported improved animal (89%; $p < 0.001$) and caretaker (91%; $p < 0.001$) quality of life were more likely to recommend cart use to others.

3.2 Complications

The overall complication rates according to the species are listed in Table 4. Across all species, 64% reported complications, and 53% of the complications were wounds. Animals fitted by a veterinarian had a higher reported complication rate (72%) than those not fitted by a veterinarian (47%; $p < 0.001$). There was no association between age of animal and complication rate across all species.

Across all cart brands, the complication rate was greater than 50%. The complication rate was significantly lower for Brands 1 and 2 compared to the remaining brands ($p < 0.001$). The specific percentages of survey response reporting complications for the six most common brands are reported on Figure 1. There was no significant relationship between the location of the wounds and the cart brand ($p = 0.05$).

The most common location for wounds to develop included the "inside of hind upper leg or thigh" followed by the "inside of upper front leg or armpit" region and "top of paws/foot." The specific locations of the wounds are summarized in Table 5.

3.3 Functional tasks

Most animals showed improved functionality when they used carts. Across all species, a higher percentage of animals were reported to have an easier time performing the functional tasks, apart from the ability to rest or sleep which was only improved for cats and rabbits. Improvement in the ability to play had the highest positive response rate across all species. Table 6 outlines the results of functional task performance across all species. There was no association between time

TABLE 5 Location of wounds associated with assistive mobility cart use.

Location	Number of wounds	Percentage of total wounds
Top of paws/foot	87	14%
Inside of hind upper leg/thigh	175	28%
Inside of upper front leg/armpit	136	22%
Belly	76	12%
Back	62	10%
Tail	39	6%
Head or Neck	42	7%
Back of ankle/hock	1	0.2%
Other	3	0.5%
Total number of wounds	621	

TABLE 6 Improvement in functional task performance across species using assistive mobility carts.

Task	Species	Yes	Total	Yes responses (%), [CI 95%]
Play	Dog	723	919	79% [76, 81%]
	Cat	177	216	82% [77, 87%]
	Rabbit	32	46	70% [56, 83%]
Eat/drink	Dog	732	918	80% [77, 82%]
	Cat	152	216	70% [64, 76%]
	Rabbit	31	46	67% [54, 81%]
Urinate	Dog	525	914	57% [54, 61%]
	Cat	140	216	65% [58, 71%]
	Rabbit	30	46	65% [51, 79%]
Defecate	Dog	493	913	54% [51, 57%]
	Cat	140	215	65% [59, 71%]
	Rabbit	27	46	61% [47, 75%]
Walk/run	Dog	676	914	74% [71, 77%]
	Cat	148	215	69% [63, 75%]
	Rabbit	24	46	52% [38, 67%]
Rest/sleep	Dog	440	914	48% [45, 51%]
	Cat	158	214	74% [68, 80%]
	Rabbit	37	46	80% [69, 92%]

of use per day and likelihood for a caretaker to recommend cart use to another caretaker across all species.

4 Discussion

In this study, the use of assistive mobility carts resulted in a perceived improvement in the quality of life of dogs and cats, as well as their caretakers. However, the use of rabbit carts did not improve the quality of life of animals or caretakers. In general, the goal of using an assistive mobility device is to improve independent mobility and interaction with the environment (2). Within animal ownership and veterinary medicine, there is an inherent dependence between an animal and its caretaker to meet basic needs (7, 11). Carts can improve functional independence, thereby alleviating the caregiver burden.

If indicated, carts may be used as a temporary aid in recovery or lifelong. Carts can be used as a part of the rehabilitation process to help keep animals in a standing position, especially when they are too weak to maintain this posture (20). As animals rebuild strength and coordination, cart use can be phased out, particularly in neurological rehabilitation. Additionally, for animals with severe spinal cord injuries, carts can assist in the development of reflexive walking by supporting the animal's weight along with other gait retraining physical rehabilitation activities (21–23). However, the use of carts remains a controversial topic. In Sweden, the use of assistive mobility carts is illegal because of the ethical concerns associated with non-ambulatory animals (13). It is not permissible to use carts, even temporarily, to assist ambulation. Further studies are necessary to determine which conditions would benefit the most from assistive mobility carts.

For humans, a variety of assistive devices can be used to improve independent mobility and comfort. Wheelchairs, walkers, and canes are analogous to assistive mobility carts for companion animals. In one study looking at adults with late-life disability, 87% of respondents stated that their quality of life was "fair," "good" or "very good" and that sense of control and dignity had the largest influence on their quality of life (24). Quality of life was also dependent on the acceptance of disability and a shift in focus to functionality, as opposed to limitations. Further research has shown that electric-powered chairs improve mobility and comfort for severely disabled people, but not independence or social interaction (3). Another study found that the use of assistive devices contributes to socioeconomic interaction, independence, and self-esteem, which are important factors for dignity (1). Challenges with assistive devices include maintenance access, infrastructure, costs, and ignorance. The stigma of using the device in public or at a place of occupation is one of the most prevalent psychological barriers (25). Assistive mobility carts may also have similar impacts on the quality of life, as seen in this study, and animals may face similar barriers to access.

Owners can be hesitant to consider carts out of concern that their pets will be unable to perform basic functions and thus have a poor quality of life. However, in this study, owners reported carts allowed animals to better perform 3 out of 4 Basic Activities for Independent Mobility (BADIM) and 4 out of 7 Instrumental Activities for Daily Quality of Life (IADQOL) described by Frye et al. (20). In addition to facilitating independent mobility, play, and eating and drinking, carts also enable animals to better posture for urination and defecation. Carts keep animals elevated during elimination and during bladder expression of incontinent animals (6, 26). In this study, the majority of caretakers stated they would recommend a cart to other caretakers, indicating the perceived value of this assistive device.

Fewer dogs had improvement in the ability to sleep or rest when using the cart compared to those who showed no improvement. The cart is designed to support a standing posture, and a completely sternal, or resting, posture is not physically possible during use. Cart use requires a caretaker to place the animal both in and out of the cart and supervise use to avoid fatigue or injury. Interestingly, responses for cats and rabbits reported overall improved ability for the animal to sleep or rest while in the cart, and this may be due to differences in size, flexibility, or conformation compared to dogs. Further observational studies are needed to better understand differences in the performance of functional tasks across companion animal species.

In terms of quality of life, there was improvement for both animals' and caretakers' quality of life for both quad and hind wheel carts. There was not a reported improvement in quality of life for either the animal or caretaker across all species for front wheel cart users. This may be related to differences in weight-bearing between the forelimbs and hindlimbs. In healthy dogs, the forelimbs bear approximately 60% of the body weight and the hindlimbs bear approximately 40% (27). For this reason, it may be easier for animals to acclimate to a hindlimb cart. For quad carts, it is possible that having the animals supported into a standing posture can make them more interactive with their surroundings and able to move with assistance or independently which would lead to improved quality of life. We suspect large dogs had the most improved animal and caretaker quality of life due to the alleviation of the greater physical burden of carrying a larger dog compared to smaller breeds. Many large breed dogs may appreciate the independence of cart activity versus a small breed dog who may be accustomed to being carried.

All assistive devices carry a risk of complications and failure of acceptance. In studies investigating veterinary prosthetic or orthotic use, skin sores, device failure or poor acceptance or compliance are commonly reported (8, 9, 28, 29). Behavioral or compliance issues may arise if the animal does not want to use the device or if the caretaker is unable or unwilling to assist the animal into the device. Specifically trained veterinary personnel with knowledge of assistive mobility carts may be used to alleviate acceptance or compliance issues.

The overall complication rate (64%) in this study was similar or lower when compared to what is reported in veterinary prosthetic and orthotic literature. In a study on socket prostheses, the short and long-term complication rates were 62 and 19%, respectively (9). In another study on both orthoses and prostheses, 91% of patients experienced at least one complication (8). The most common complications cited were skin complications, mechanical issues and non-acceptance by the patient.

In the current study, the most common location for wounds to develop was the inner thigh, followed by the axillary region and the tops of the paw or feet. This result is likely due to contact with the supporting saddle, harness of the cart and contact with the ground. The saddles are generally constructed out of rubber or other firm materials. In addition, many animals using carts are incontinent, posing a greater challenge in maintaining skin hygiene. Further research into the use of different materials to line these areas is needed to help reduce wound development in these high-contact areas. A high prevalence of wounds forming on the tops of the paws is suspected to be due to the dragging of the paw on abrasive flooring. Paw wounds can be prevented by applying protective footwear or sling supports to prevent foot contact with the floor. Species variation in terms of skin thickness or fur type can contribute to formation of wounds. Specific carts are generally designed for a specific species of animal which can also impact the overall fit and lead to wounds or other complications. Further studies looking into these variables are needed to better understand the impact on wound development.

We were surprised to find that dogs who were fitted by a veterinarian experienced a higher incidence of complications. This may in part be due to selection bias; more challenging cases may be more likely to present for veterinary care. Another consideration is the variability of veterinary training. Rehabilitation is not included in the core veterinary curriculum of most veterinary schools, and thus, veterinarians generally lack exposure to assistive devices. Training programs range from rehabilitation certification to board certification (Diplomate of the American College of Veterinary Sports Medicine and Rehabilitation). Even with advanced rehabilitation training, assistive mobility cart fitting education is not standardized. Moreover, veterinarians often only observe animals in a clinic setting, limiting the ability to troubleshoot acclimatization and fitting challenges that may occur exclusively in the home environment.

Positive reinforcement and physical rehabilitation focused on the appropriate device use are generally recommended to improve success. Behavioral acclimation to ensure cart acceptance is critical, especially in cases when a cart is the only way an animal can ambulate independently (4). Future prospective studies investigating the impact of rehabilitation programs guiding cart use are warranted.

There were several limitations inherent to the survey-based nature of this study. Information was self-reported by caretakers and medical indications were not confirmed via medical records. This can especially impact the reason for use and complication variables. There could have been a selection bias of respondents based on their experiences with cart use. Caretakers with very good or very poor experiences may be more likely to participate in the survey. Additionally, incentivized surveys can be susceptible to spurious or "bot" responses. To limit this possibility, a "bot" response detection service from the Qualtrics platform was applied to filter sham responses. Survey question interpretation was dependent on the participant and may have been variable. This may have influenced responses and may have differed from the author's intended goal of the question. The single-use survey format may have excluded additional data from animals that have used multiple brands or types of carts. The use of binary response (yes/no) questions may have oversimplified more nuanced answers and should be avoided in future surveys to avoid leading questions. Another limitation was not requesting the training levels of the veterinarians involved in the cart fitting. Future studies are required to investigate the impact of how guidance from a board-certified veterinary sports medicine and rehabilitation specialist impacts cart complication and acceptance rates.

5 Conclusion

Based on this survey study, assistive mobility carts improved the quality of life of dogs and cats with mobility disorders and of their caretakers. There was no improvement in quality of life for the majority of rabbits or their caretakers. Carts are generally well-accepted and facilitate activities of daily living. Similar to veterinary orthotics and prosthetics, wounds are the most commonly reported complication. Future studies exploring the impact on patient outcomes and factors influencing success, acceptance and complication rates are needed to guide clinical recommendations.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The animal study was approved by Institutional Review Board - University of Florida. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

MN: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing – original draft, Writing – review & editing. JR: Conceptualization, Methodology, Project administration, Supervision, Visualization, Writing – review & editing, Investigation. EM: Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

James Colee, MS, of the University of Florida's Statistical Consulting Unit Institute of Food and Agricultural Sciences for statistical analysis.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2024.1466405/full#supplementary-material

References

1. Borade N, Ingle A, Nagarkar A. Lived experiences of people with mobility-related disability using assistive devices. *Disabil Rehabil Assist Technol*. (2021) 16:730–4. doi: 10.1080/17483107.2019.1701105

2. Cowan , Fregly BJ, Boninger ML, Chan L, Rodgers MM, Reinkensmeyer DJ. Recent trends in assistive technology for mobility. *J Neuroeng Rehabil*. (2012) 9:20. doi: 10.1186/1743-0003-9-20

3. Davies A, De Souza LH, Frank AO. Changes in the quality of life in severely disabled people following provision of powered indoor/outdoor chairs. *Disabil Rehabil*. (2003) 25:286–90. doi: 10.1080/0963828021000043734

4. Magidenko SR, Peterson NW, Pisano G, Buote NJ. Analysis of patient outcome and owner satisfaction with double limb amputations: 14 dogs and four cats. *J Am Vet Med Assoc*. (2022) 260:884–91. doi: 10.2460/javma.21.04.0199

5. Marcellin-Little DJ, Drum MG, Levine D, McDonald SS. Orthoses and exoprostheses for companion animals. *Vet Clin North Am Small Anim Pract*. (2015) 45:167–83. doi: 10.1016/j.cvsm.2014.09.009

6. Olby NJ, Moore SA, Brisson B, Fenn J, Flegel T, Kortz G, et al. ACVIM consensus statement on diagnosis and management of acute canine thoracolumbar intervertebral disc extrusion. *J Vet Intern Med*. (2022) 36:1570–96. doi: 10.1111/jvim.16480

7. Sedlacek J, Rychel J, Giuffrida M, Wright B. Nonsurgical rehabilitation in dachshunds with T3-L3 myelopathy: prognosis and rates of recurrence. *Front. Vet. Sci.* (2022) 9:934789. doi: 10.3389/fvets.2022.934789

8. Rosen S, Duerr FM, Elam LH. Prospective evaluation of complications associated with orthosis and prosthesis use in canine patients. *Front. Vet. Sci.* (2022) 9:892662. doi: 10.3389/fvets.2022.892662

9. Wendland TM, Seguin B, Duerr FM. Retrospective multi-center analysis of canine socket prostheses for partial limbs. *Front. Vet. Sci.* (2019) 6:100. doi: 10.3389/fvets.2019.00100

10. Wendland TM, Seguin B, Duerr FM. Prospective evaluation of canine partial limb amputation with socket prostheses. *Vet. Med. Sci.* (2023) 9:1521–33. doi: 10.1002/vms3.1146

11. Freeman PM, Holmes MA, Jeffery ND, Granger N. Time requirement and effect on owners of home-based management of dogs with severe chronic spinal cord injury. *J Vet Behav*. (2013) 8:439–43. doi: 10.1016/j.jveb.2013.06.001

12. Lee S, Wendland TM, Rao S, Magee C. Orthotic device use in canine patients: owner perception of quality of life for owners and patients. *Front. Vet. Sci.* (2021) 8:709364. doi: 10.3389/fvets.2021.709364

13. Mojarradi A, De Decker S, Bäckström C, Bergknut N. Safety of early postoperative hydrotherapy in dogs undergoing thoracolumbar hemilaminectomy. *J Small Anim Pract*. (2021) 62:1062–9. doi: 10.1111/jsap.13412

14. Olby NJ, da Costa RC, Levine JMStein VM and the Canine Spinal Cord Injury Consortium (CANSORT SCI). Prognostic factors in canine acute intervertebral disc disease. *Front Vet Sci*. (2020) 7:596059. doi: 10.3389/fvets.2020.596059

15. Rossi G, Stachel A, Lynch AM, Olby NJ. Intervertebral disc disease and aortic thromboembolism are the most common causes of acute paralysis in dogs and cats presenting to an emergency clinic. *Vet Rec*. (2020) 187:e81. doi: 10.1136/vr.105844

16. Kobatake Y, Nakata K, Sakai H, Sasaki J, Yamato O, Takashima S, et al. The long-term clinical course of canine degenerative myelopathy and therapeutic potential of curcumin. *Vet Sci*. (2021) 8:192. doi: 10.3390/vetsci8090192

17. Mich PM. The emerging role of veterinary orthotics and prosthetics (V-OP) in small animal rehabilitation and pain management. *Top Companion Anim Med*. (2014) 29:10–9. doi: 10.1053/j.tcam.2014.04.002

18. Wright A, Amodie DM, Cernicchiaro N, Lascelles BDX, Pavlock AM, Roberts C, et al. Identification of canine osteoarthritis using an owner-reported questionnaire and treatment monitoring using functional mobility tests. *J Small Anim Pract*. (2022) 63:609–18. doi: 10.1111/jsap.13500

19. Creevy K, Grady J, Little S, Moore G, Strickler B, Thompson S, et al. 2019 AAHA Canine Life Stage Guidelines. *J Am Anim Hosp Assoc*. (2019) 55:267–90. doi: 10.5326/JAAHA-MS-6999

20. Frye C, Carr BJ, Lenfest M, Miller A. Canine geriatric rehabilitation: considerations and strategies for assessment, functional scoring, and follow up. *Front. Vet. Sci.* (2022) 9:842458. doi: 10.3389/fvets.2022.842458

21. Gallucci A, Dragone L, Menchetti M, Gagliardo T, Pietra M, Cardinali M, et al. Acquisition of Involuntary Spinal Locomotion (spinal walking) in dogs with irreversible thoracolumbar spinal cord lesion: 81 dogs. *J Vet Intern Med*. (2017) 31:492–7. doi: 10.1111/jvim.14651

22. Lewis MJ, Jeffery ND, Olby NJthe Canine Spinal Cord Injury Consortium (CANSORT-SCI). Ambulation in dogs with absent pain perception after acute thoracolumbar spinal cord injury. *Front. Vet. Sci.* (2020) 7:560. doi: 10.3389/fvets.2020.00560

23. Martins Â, Silva CM, Silva CM, Gouveia D, Cardoso A, Coelho T, et al. Spinal locomotion in cats following spinal cord injury: a prospective study. *Animals*. (2021) 11:1994. doi: 10.3390/ani11071994

24. King J, Yourman L, Ahalt C, Eng C, Knight SJ, Pérez-Stable EJ, et al. Quality of life in late-life disability: "I don't feel bitter because I am in a wheelchair". *J Am Geriatr Soc*. (2012) 60:569–76. doi: 10.1111/j.1532-5415.2011.03844.x

25. Saia T, Vogel E, Salazar S. "We need a world we can operate in": exploring the relationship between societal stigma and depression among wheelchair users. *Disabil Health J*. (2024) 17:101624. doi: 10.1016/j.dhjo.2024.101624

26. Jeffery N, Levine J, Olby N, Stein V. Intervertebral disk degeneration in dogs: consequences, diagnosis, treatment, and future directions. *J Vet Intern Med*. (2013) 27:1318–33. doi: 10.1111/jvim.12183

27. Bockstahler BA, Skalicky M, Peham C, Müller M, Lorinson D. Reliability of ground reaction forces measured on a treadmill system in healthy dogs. *Vet J*. (2007) 173:373–8. doi: 10.1016/j.tvjl.2005.10.004

28. Carr BJ, Canapp S, Petrovitch JL, Campana D, Canapp D, Leasure CS. Retrospective study on external canine limb prosthesis used in 24 patients. *Vet Evid*. (2018) 3:1–13. doi: 10.18849/ve.v3i1.118

29. Phillips A, Kulendra E, Bishop E, Monk M, Parsons K, House A. Clinical outcome and complications of thoracic and pelvic limb stump and socket prostheses. *Vet Comp Orthop Traumatol*. (2017) 30:265–71. doi: 10.3415/VCOT-16-09-0127

frontiers | Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 04 December 2024
DOI 10.3389/fvets.2024.1492391

Check for updates

OPEN ACCESS

EDITED BY
Christian Peham,
University of Veterinary Medicine Vienna, Austria

REVIEWED BY
Sarah Love,
Sport Dog Specialty Medicine, Yampa, United States
Jacqueline Boyd,
Nottingham Trent University, United Kingdom
Bess Pierce,
University of Missouri, United States

*CORRESPONDENCE
Arielle Pechette Markley
ariellemarkley@gmail.com

RECEIVED 06 September 2024
ACCEPTED 21 November 2024
PUBLISHED 04 December 2024

CITATION
Pechette Markley A, Wood MK, Shoben AB and Olson RA (2024) Variability in performance of agility dogs navigating a dynamic obstacle.
Front. Vet. Sci. 11:1492391.
doi: 10.3389/fvets.2024.1492391

Variability in performance of agility dogs navigating a dynamic obstacle

Arielle Pechette Markley[1,2]*, Moriah K. Wood[3], Abigail B. Shoben[4] and Rachel A. Olson[3]

[1]Department of Veterinary Clinical Sciences, College of Veterinary Medicine, The Ohio State University, Columbus, OH, United States, [2]Red Sage Integrative Veterinary Partners, Fort Collins, CO, United States, [3]Department of Biology, The University of Akron, Akron, OH, United States, [4]College of Public Health, Division of Biostatistics, The Ohio State University, Columbus, OH, United States

Introduction: During agility performance, dogs complete a preset obstacle course. The teeter, also known as the seesaw, is the only dynamic contact obstacle. Dogs handle dynamic obstacles differently than static obstacles due to the need for increased coordination and postural control. No studies have been performed evaluating dogs' abilities or biomechanical strategies to navigate the teeter. The goal of this study was to describe and quantify variability in teeter performance across a sample of dogs of differing body mass and breeds.

Materials and methods: Twenty dogs of various body masses and breeds were recruited. Handlers were instructed to line their dog up approximately 5 m from the teeter and to handle the obstacle in a way to best reflect the dog's typical performance. Repetitions were filmed using a GoPro Hero 11 at 240 frames per second. Data were post processed and footfalls were manually tracked using XMALab. Descriptive statistics were used to describe both central tendency and variability.

Results: Mean total obstacle completion time (from dog breaking the plane of the teeter until teeter contact with ground) was 1.31 s (sd = 0.38) and mean total footfalls on the teeter was 18.3 (sd = 3.4). Footfall patterns varied across all phases of teeter performance, with particularly noteworthy variation during descent while the teeter was moving. Some dogs were nearly completely stationary while the teeter dropped while others continued to take steps toward the end of the obstacle as the teeter was in motion. Smaller dogs had more total footfalls and longer teeter completion times than larger dogs, and dogs with a stopped contact behavior took longer to fully exit the teeter after it contacted the ground.

Discussion: These data imply that dogs use a variety of biomechanical strategies to perform a dynamic obstacle. Results of this study provide insight into teeter performance and variables that can be utilized for evaluation in future biomechanical studies. This study also provides initial data on biomechanical strategies used by dogs on dynamic surfaces, which may offer insight into dynamic stability and postural control in dogs and how that may influence injury development during sport.

KEYWORDS

agility, dog, teeter, sports performance, canine sports medicine, biomechanics, dog agility, seesaw

1 Introduction

The canine discipline of agility is popular internationally, with over 1.2 million competition entries in American Kennel Club (AKC) sanctioned events alone in 2023 (1). During agility performance, dogs complete a course of obstacles in a pre-designated, specific order. These obstacles may include jumps, tunnels, weave poles, and contact equipment (A-frame, teeter, dog walk). Contact obstacles require the dog to enter on one end and exit the other end by placing at least a portion of one paw in the yellow "contact zone" at the end of the exit board. Agility is a test of both speed and training, with errors receiving faults or a time penalty, and the fastest time winning.

The teeter, also known as the seesaw, is the only dynamic contact obstacle. The teeter consists of a plank, usually made of fabricated material, though older designs used wood, which is typically coated in a rubber skin. This plank is supported at the center by a base that acts as a fulcrum (2). Equipment specifications vary by agility organization. In general, the teeter plank is 12 inches wide and 12 feet long and is required to have a non-slip surface. The height of the teeter is 24″ at the pivot point. For the AKC, the designated "contact zones" are 36 inches long and are colored in contrasting color from the remainder of the plank. AKC regulations require that the teeter is specifically designed so that it is balanced and hits the ground in less than 3 s when a 3-pound weight is placed 12 inches from the raised end (2). The event organizer must have on-hand the materials to correct a slow-dropping teeter (duct tape/fasteners, weights, etc.) (2). Dogs must ascend the plank and then cause the plank to pivot. In AKC, dogs must touch the "up" contact zone with any part of one foot, though other agility organizations do not have "up" contact zone requirements (2). For all agility organizations, at least one paw must touch the "down" contact zone after the plank has touched the ground prior to exiting the obstacle with all four paws (2). The dog must exit the descent end of the teeter. Standard faults (point/time deductions) are given if the dog misses the up (in AKC) or down contact zone, or if the dog jumps off the end of the teeter plank before the board contacts the ground (called a "fly-off") (2).

A variety of training strategies are employed for this obstacle. To ensure successful completion of the obstacle, where the teeter touches the ground and the dog has at least one paw in the "down" contact, many handlers train the dog to perform a specific behavior at the end of the teeter, also called a contact behavior (Figure 1). The two most commonly trained behaviors include a "two-on two-off" (2o2o; Figure 1C) and an "all four on standing" (4o; Figure 1B), with the overwhelming majority performing a "two-on two-off" behavior (3). The 2o2o behavior is where the dog is trained to run to the end of the plank, place the two front feet on the ground off the plank while keeping the rear two feet on the down contact. Typically, the dog is trained to remain in that position until verbally released. A 4o behavior is where the dog is trained to run to the end of the plank and stop with all 4 paws on the plank as close to the end as possible, either in a standing position (more common), a down or a bow position (less common) and the position is typically held until released by the handler. A running contact is also performed by some dog-handler teams, where no stop is performed after the plank contacts the ground, and requiring no release, although the dog is often stationary during descent (Figure 1D). Some handlers train with a stationary contact behavior (2o2o or 4o) but will do a quick/early release, where typical contact criteria are not upheld in exchange for speed, or running contact during major competitions. Methods for training these various contact behaviors vary. A successful performance reflects the dog's physical, and mental, ability to compensate for the dynamic obstacle movement. A failure to successfully perform this obstacle will result in the best case, a time penalty, and in the worst case, injury to the dog.

Injuries are common in agility dogs, with some studies reporting up to a 42% injury rate (4). Shoulder, iliopsoas muscle, digit and lower back injuries were most commonly reported (4). While other studies have evaluated possible risk factors for injury, minimal clear correlations have been observed. The most consistent correlations across studies have been

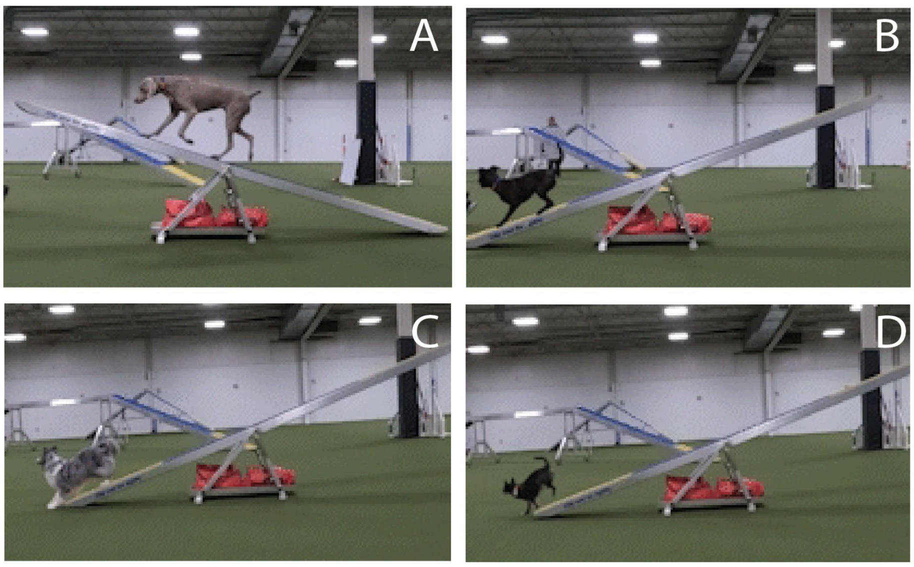

FIGURE 1
Images of teeter performance. **(A)** A dog crossing the pivot point of the teeter, **(B)** a dog performing a "all four on standing" (4o) behavior, **(C)** a dog performing a "two-on two-off" (2o2o) behavior, and **(D)** a dog performing a running contact.

increased risk of injury with Border Collie breed, higher competition level, less handler experience, and increased dog weight compared to height (3, 5–10). There have been very few correlations found between injury and specific obstacle performance. However, one study found that dogs who completed training for teeter contact behavior at a younger age had a lower risk of injury (3). The reasons for this were unknown, but one of the hypotheses was that dogs who were able to learn to negotiate the teeter quickly had better balance and coordination compared to dogs who took longer to learn to navigate this dynamic obstacle. In humans, increased balance and coordination has been shown to be associated with decreased risk of injury in athletes (11).

There has been much discussion among the agility community about how specific obstacles, performance techniques, and contact behaviors for those obstacles might influence injury risk. However, to date, there have been no studies specifically evaluating these factors. A study by Cullen et al., asked handlers in a retrospective survey if they thought a specific obstacle was associated with their dog's injury (12). Commonly reported perceived causes of injury included direct contact with a bar jump and contact with/fall from an A-frame or dog walk (12). Based on these concerns, some biomechanical studies have been performed looking at kinetics and kinematics of jumping and A-frame performance, but none have looked at specific paw placement patterns, contact behaviors, or relationship to injury (13–26). Other video-based studies have aimed to look at paw placement patterns in the performance of obstacles such as weave poles and the dog walk with the intent of categorizing performance strategies to enable more in-depth studies. Those studies found that weave pole performance could generally be classified into 5 specific techniques, but that dog walk performance was too variable for classification (27, 28). However, due to the unique, dynamic nature of the teeter obstacle, studies evaluating other obstacles cannot be extrapolated to the teeter. Currently, no studies have been performed evaluating performance strategies, kinetics, or kinematics of the teeter obstacle.

The dynamic nature of the teeter obstacle makes it a unique obstacle to navigate. No studies have been performed evaluating dogs' abilities or biomechanical strategies to navigate dynamic obstacles. A recent study evaluated the effect of external mechanical perturbations using a motorized training platform on a dog's postural stability (29). Center of pressure was used to measure postural stability and, not surprisingly, it was found that external mechanical perturbations created a challenge for postural stability. They also found that an increase in amplitude of the perturbations created a greater challenge for postural stability than an increase in speed of the perturbations (29). This study noted that dogs did not tolerate the highest intensities of amplitude and speed in combination. It is unknown if or how a mechanical platform correlates with the movement and postural control needs for performance of the teeter obstacle. Other studies in dogs have evaluated how aging affects postural control, and how orthopedic surgery affects balance (30–32). However, neither of these populations are particularly relevant to the canine athlete population navigating dynamic obstacles. There is a very large body of research on dynamic stability and postural control in humans, in a variety of demographic populations including athletes. However, results are likely to be different based on bipedal versus quadrupedal biomechanics.

The goal of this study was to describe and quantify variability in different teeter performance strategies across a convenience sample of dogs of differing body mass and breeds, and to identify areas of interest for future biomechanical studies.

2 Materials and methods

2.1 Data collection

Twenty dogs without breed or size restriction were recruited for this study. All dogs were owner-reported to be competing at the Masters level of AKC agility (or equivalent) and to be free of orthopedic health conditions. The owner also reported breed, height at the withers, and mass.

The training facility was a 12,000 square foot, indoor, climate-controlled building used almost exclusively for dog agility training and competitions. The footing was GrassTex turf (product PL307). The teeter was a "Clip and Go Seesaw" which is an engineered rigid aluminum plank with a metal MAX/composite board top on the plank and a wet-pour UV-stable rubber surface. It has speed-limiting, cushioning cylinders on base to reduce board whip and rebound (cylinders are sealed), nylon pivot bushings on base, and energy-absorbing foam underneath the grip pads on the descent side of plank to cushion impact. The teeter was secured with sandbags on the fulcrum to limit extraneous movement, as is common in agility competitions. The drop rate of the Clip and Go Seesaw in the standard 3 lb.-weight test ranges from 1.6 to 1.9 s (33).

Handlers were instructed to line their dog up approximately 5 m away from the teeter and to handle the obstacle in a way of their choosing to best reflect the dog's typical performance. Dogs were asked to perform a total of four repetitions of the teeter, two each with the handler on the left and right sides of the dog. Only a single repetition of the obstacle was performed per recording sequence. Dogs were filmed using GoPro Hero 11 at 240fps in linear mode while performing the obstacle.

All protocols were approved by the Ohio State University's institutional animal care and use committee (IACUC #2022A00000058).

2.2 Data processing

Data was post-processed and footfalls were manually tracked using XMALab (version 2.1.0) for a single repetition for each dog with the handler on the right, so as to not obscure the dog's performance. For each footfall, the position on the obstacle/ground and the duration of contact with the obstacle/ground (i.e., duty factor) was recorded. For positional footfalls, four areas of interest on the teeter were defined: the up-contact zone, the area past the up-contact but prior to the midpoint, the area past the midpoint but prior to the down contact zone, and the down contact zone. Per AKC rules, contact with any portion of the paw within the yellow contact zone (up or down) was considered a footfall within the contact zone. Total footfalls on the teeter were also recorded.

For the purpose of defining performance strategies, the following phases of teeter performance were described: 1. Approach; 2. Ascent; 3. Tip; 4. Descent; 5. Exit. Approach was defined as the stride before any contact with the teeter. Ascent was defined as the time between the dog's nose breaking the plane of the teeter and when the teeter started to move. Tip was defined as the instantaneous moment the teeter began to move. Descent was defined as the time between when the teeter began to move to when it contacted the ground. Exit was defined as the time from when the teeter contacted the ground to the stride after all paws have left contact with the teeter. This may include a stationary period where the dog is holding a contact behavior.

Duty factor footfalls were counted within ascent, descent, and exit. When counting footfalls in these time intervals, a footfall held over two time intervals (e.g., both the ascent and descent) was classified based on where it was held longer. For these footfalls, resetting of paws were counted as a single footfall when they were not visually distinct on a duty factor plot. Note that footfalls on the ground before and after dog contact with the plank were not counted as total footfalls, but footfalls on the ground during exit (i.e., as part of a stationary contact behavior) were counted as duty factor footfalls.

Contact behaviors were defined as "stopped" or "not stopped." A dog that had all four paws simultaneously stationary with at least one paw on the teeter after the teeter had contacted the ground was considered to have a "stopped" contact. The stopped contact behavior was further classified based on how many paws remained on the teeter while stopped: "4 on" (4o) if all four paws were on the teeter, "2 on 2 off" (2o2o) if the front paws were off and rear paws were still on, and "3 on 1 off" (3o1o) if 3 paws were on the teeter and one front limb was off. Sliding was not observed in any of the dogs in this study.

"Total time to completion" was defined as the time from when the dog's nose broke the plane of the teeter until the teeter first contacted the ground (i.e., ascent time + teeter descent time). "Time to dog exit" was defined as the time from when the teeter first contacted the ground until no more paws were in contact with the obstacle. Additionally, "dog time to descent" was defined as the time from when the nose crossed the midpoint until the teeter touched the ground, whereas "teeter time to descent" was defined as the time from when the teeter started to move until it touched the ground (i.e., "descent" phase above). All times were calculated by counting the number of frames and converting to seconds.

2.3 Data analysis

Descriptive statistics were used to describe both central tendency (means) and variability (standard deviations, range). Dogs were grouped into 4 mass categories (<10 kg, 10–20 kg, 20-30 kg, and > 30 kg). Mass was chosen for categorical representation of dog size, as teeter descent is dependent on mass past the pivot point. Exploratory associations between dog mass and teeter performance variables were quantified with linear regression models. Statistical analysis and plots were performed in RStudio (version 2023.12.0 + 369) using the packages proxy (version 4.3.2), spatstat.geom (version 4.3.2), tidyr (version 4.3.2), and plotly (version 4.3.2).

3 Results

3.1 Overall teeter performance

The 20 participating dogs were a variety of breeds and sizes (full raw data available in Supplementary Tables 1, 2). The most common breed was the Border Collie ($n = 6$), but the sample also included four Labrador Retrievers, three mixed breed dogs, and three Weimaraners. The mean mass was 20.5 kg (sd = 8.9) with the smallest being a 4.0 kg Italian Greyhound and the largest a 39.6 kg Weimaraner. A stopped contact was observed for 13 of the 20 dogs (65%). The remaining dogs did not have a stopped contact, but a variety of "not stopped" behaviors were observed. The two smallest dogs (<10 kg) did not have a stopped contact and the two largest dogs (>30 kg) both did have a stopped contact.

The mean total time for obstacle completion was 1.31 s (sd = 0.38), with a minimum of 0.96 s and a maximum of 2.55 s observed (Table 1). Total obstacle completion times were generally similar between dogs with stopped contacts and those without (Table 1). The mean number of duty factor footfalls was 18.3 (sd = 3.4), with a minimum of 12 and a maximum of 26, and these means were also similar between dogs with and without stopped contacts (Table 1). Dog mass was strongly associated with both total footfalls and obstacle performance times. Larger dogs had fewer total

TABLE 1 Summary statistics for obstacle performance time in seconds and number of observed footfalls in each teeter phase.

	All dogs° (n = 20)	Min, Max	Stopped° (n = 13)	Not stopped° (n = 7)
Overall				
Total obstacle completion time*	1.31 (0.38)	0.96, 2.55	1.21 (0.12)	1.50 (0.60)
Total number of footfalls	18.3 (3.4)	12, 26	18.8 (1.9)	17.4 (5.3)
Ascent				
Ascent time‡	0.61 (0.22)	0.32, 1.11	0.58 (0.18)	0.68 (0.28)
Ascent number of footfalls	6.2 (2.2)	4, 13	5.6 (1.2)	7.1 (3.2)
Descent				
Teeter time to descent†	0.70 (0.23)	0.51, 1.44	0.63 (0.12)	0.83 (0.33)
Dog time to descent#	0.90 (0.31)	0.65, 1.93	0.80 (0.10)	1.07 (0.48)
Descent number of footfalls	5.9 (2.4)	2, 12	5.6 (2.7)	6.4 (1.9)
Exit				
Time to dog exit^	1.24 (0.92)	0.02, 3.47	1.75 (0.77)	0.37 (0.23)
Exit number of footfalls	6.3 (2.9)	1, 11	7.5 (2.6)	3.9 (1.6)

*Time from when nose crosses teeter threshold until teeter touches the ground.
‡Time from when nose crosses teeter threshold until teeter starts to move.
†Time from when teeter starts to move until teeter touches the ground.
#Time from when nose crosses midpoint until teeter touches the ground.
^Time from when teeter touches ground to last paw contact (n = 19 total; 1 stopped contact still held on video end).
°Mean (SD).

footfalls (Figure 2; $p = 0.012$). Larger dogs also had faster overall total obstacle completion times (Figure 3; $p = 0.011$). Paw positions on the teeter plank for all 20 dogs are shown in Figure 4 and the corresponding duration of each footfall (duty factor) is illustrated in Figure 5.

3.2 Approach

Dogs appeared to show some variability in their entry stride into the teeter (Figures 4, 5). Some individuals (WEIM_001, DOB0_0001) had all four footfalls within a relatively small space on the ground close to the teeter, indicating more of a collection-type stride. Others (e.g., BC00_0006, LAB_0004) took the entry stride from further away and had a longer stride length, indicating greater relative extension. All dogs appeared to have average-to-short contact duration with the ground during the entry stride, as compared to their footfalls while on the teeter (Figure 5).

3.3 Ascent

Mean time for ascent was 0.61 s (sd = 0.22), with all dogs initiating the tip within 1.11 s. Initial paw positioning was variable during teeter ascent, with two dogs not placing any paws in the up-contact zone and nine individuals placing all four paws at least once in this region (Figure 4). Mean total number of footfalls during ascent was 6.2, with slightly more footfalls observed during ascent for dogs without stopped contacts (7.1 footfalls) than dogs with stopped contacts (5.6 footfalls). However, mean footfalls during ascent were virtually identical between the 13 dogs with stopped contacts, all of whom had a mass > 10 kg, and the 5 dogs with mass > 10 kg who did not have a stopped contact. The footfalls during ascent were generally short in duration relative to the footfalls during descent (Figure 5), although for some individuals there was an observed increase in contact time just prior to the tip point as well (e.g., MIX0_001).

3.4 Tip

The location of the dog when the teeter started to move is shown in Figure 6. Some dogs initiated the tip near the midpoint of the teeter while others took a stride spanning the midpoint and initiated contact further along the plank. This variation was seen even within dogs of the same breed (e.g., LAB0_0001, LAB0_0002).

3.5 Descent

The mean time for dog descent was 0.90 s (sd = 0.31, Table 1) and the mean time for teeter descent was 0.70 s (sd = 0.23, Table 1). The fastest teeter descent time was 0.51 s, with multiple dogs approaching 0.5 s (Figure 7). 15 of 20 dogs (75%) had times less than 0.75 s (Figure 7 and Supplementary Table 2). Descent times were longer for the smallest dogs with statistically significant associations observed between mass and dog descent time (Figure 8A; $p = 0.002$) and dog mass and teeter descent time (Figure 8B; $p < 0.001$).

Dogs appeared to use a variety of biomechanical strategies to navigate the moving plank during descent (area between the solid and dashed lines in Figure 5). Some dogs maintained a near-stationary position with long duty factors (e.g., MIX0_0001, MIX0_0003, BC00_0007), while others took multiple steps while the teeter was in motion (e.g., IG00_0001, SS00_0001). Often, larger dogs straddled the pivot point of the teeter during descent while smaller dogs stood further past the midpoint until the teeter contacted the ground, as seen from the still images in Figure 6 and the corresponding paw timings in Figure 5.

The mean number of footfalls during the descent (5.9, sd = 2.4) was similar to the mean number of footfalls during ascent (6.2, sd = 2.2) and generally similar between dogs with stopped and not stopped contacts (Table 1). All dogs contacted the down contact zone with multiple paws in this sample (Supplementary Table 1).

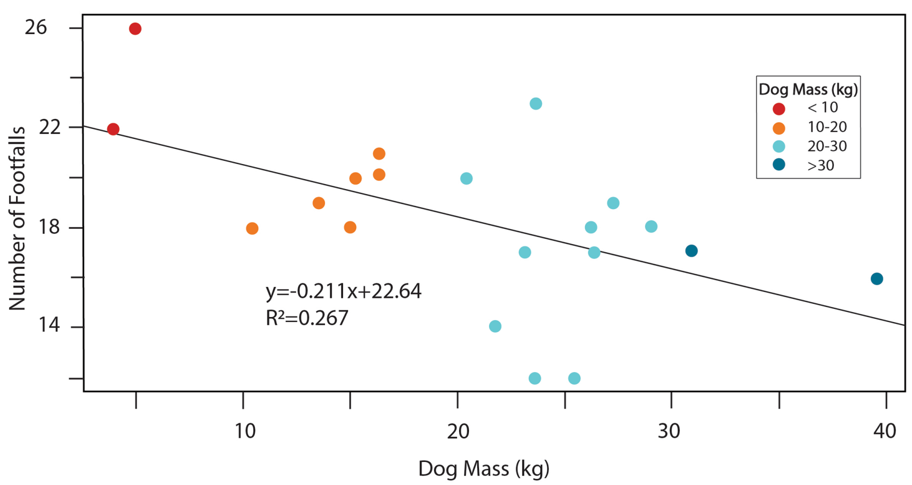

FIGURE 2
A relationship between dog body mass and the total number of footfalls was observed, with a trend of larger dogs having fewer footfalls than smaller ones ($p = 0.012$). Color coding indicates mass categories.

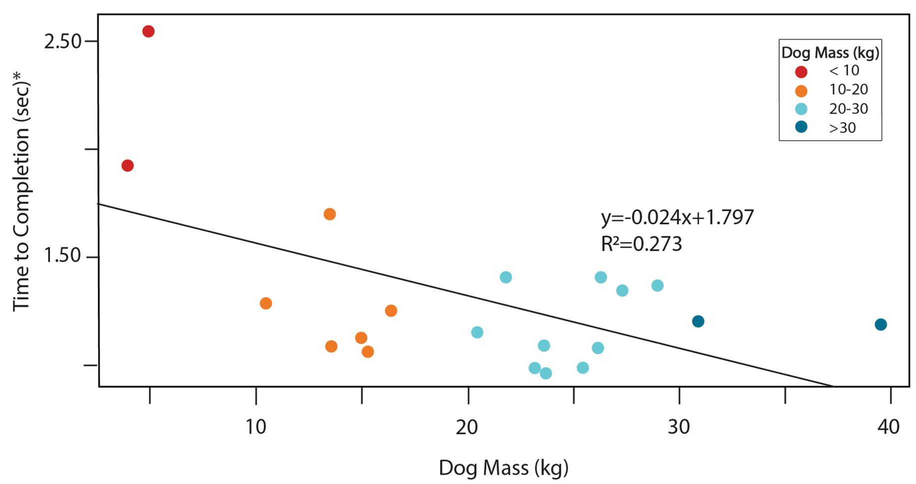

FIGURE 3
Scatterplot with superimposed linear regression line showing the association between dog mass and total obstacle completion time* (p = 0.011). Color coding indicates mass categories.

3.6 Exit

Of the 13 dogs with a stopped contact, 11 (85%) were classified as a 2o2o contact. In this controlled environment, dogs held stopped contact behaviors for varying amounts of time with a mean time to exit of 1.24 s (sd = 0.92) among dogs with stopped contacts (Table 1). One dog (BC00_0006) did not exit the obstacle during the video and was still holding a 2o2o.

Dogs with a stopped contact had more footfalls during the exit phase as compared to dogs without a stopped contact (Table 1). Some dogs were observed shifting their weight or taking small steps while maintaining the same contact behavior (e.g., the multiple blue footfalls in Figure 4: for DOB0_0002 and WEIM_0002).

The exit stride, or the first stride off the teeter, showed high variability in paw positioning, as illustrated on Figure 4. Some of this variability appears to be related to contact behavior, with dogs who had a 2o2o stopped contact placing their paws further from the exit edge of the teeter plank.

4 Discussion

The goal of this study was to describe and quantify variability in different teeter performance strategies across a sample of dogs of differing body mass and breeds and to identify areas of interest for future biomechanical studies. Dogs exhibited a substantial amount of variability in paw positioning, number of footfalls, duty factor, and obstacle performance times. There was considerable variability in biomechanical strategies for each phase of the teeter and notable differences in performance observed between the smallest and largest dogs.

4.1 Approach

Observationally, there was substantial variation in entrance strides between dogs, particularly with regards to the degree of collection and extension (i.e., relative stride length) exhibited upon entrance to the teeter (Figure 4). Visually, some of the Border Collies and Labrador Retrievers in this study entered the teeter with more extension compared to others of the same breed. Similarly, some Weimaraners, Doberman, and mixed dogs appeared to enter the teeter with more collection compared to others in their mass category. This variation may be a result of training methods or breed behavior, as this did not appear to be associated with mass. However, this study evaluated obstacles independently, with a straight-line approach, and not in sequence. Agility courses will have varying angles of approach to the teeter, as well as variations in speed of approach based on the previous obstacle type, orientation and the distance from the previous obstacle to the teeter. These variations in course design will likely affect the approach performance variables such as the degree of collection or extension. Approach stride lengths were not quantified as dogs started a relatively short distance from the teeter obstacle from a stationary position which is not representative of obstacle completion during typical agility obstacle performance. Therefore, these observations were based on visual estimations and were not corrected to actual stride lengths. Additional studies would be needed to evaluate entrance stride kinematics and relation to breed, conformation, training, and course design.

4.2 Ascent

Footfall placement and number of footfalls during the ascent phase was quite variable between dogs. Two dogs did not place any paws in the up-contact zone. In AKC, where the up-contact zone is judged, this would be considered a fault, though these two dogs questionably placed toes on the edge of the plank in the up-contact, so it may not have been judged as a fault. Some dogs placed a single paw in the up-contact zone but almost half of dogs had a whole stride (placement of all four paws) within the up-contact zone. The paw placements within the up-contact zone were correlated with dog size, with smaller dogs more likely to complete a whole stride in the up-contact. The two dogs that did not place a paw in the up-contact

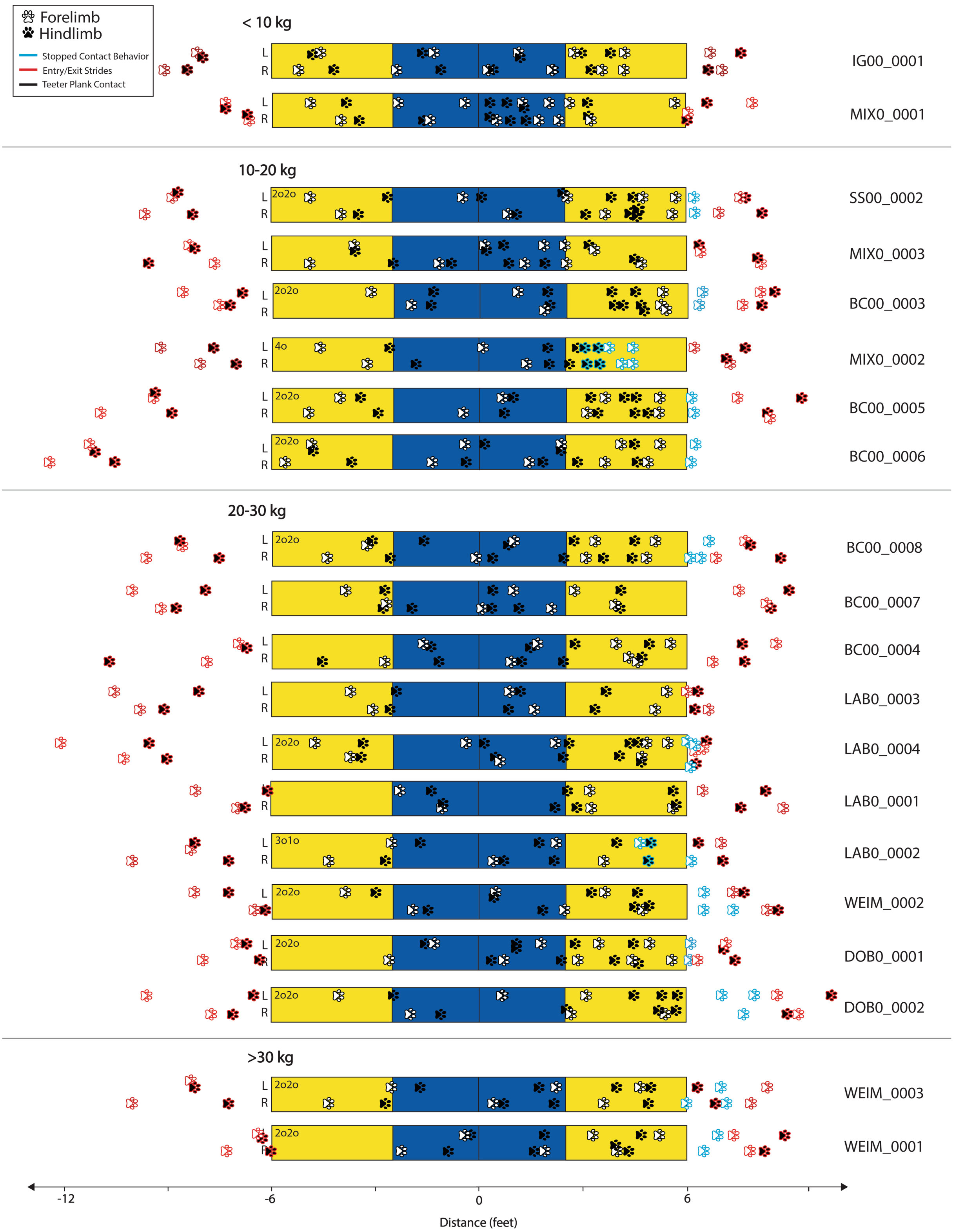

FIGURE 4
Paw position on the teeter obstacle for all 20 dogs. Front paws are shown with white fill and rear paws are shown with black fill. The strides before and after are shown in red and observed stopped contact behaviors are shown as blue outlines (2o2o, 4o, 3o1o), indicating that the dog was stationary after the teeter touched the ground. Dogs are separated by mass category (<10 kg, 10–20 kg, 20–30 kg, >30 kg). BC00_0006 held 2o2o stopped contact on video end.

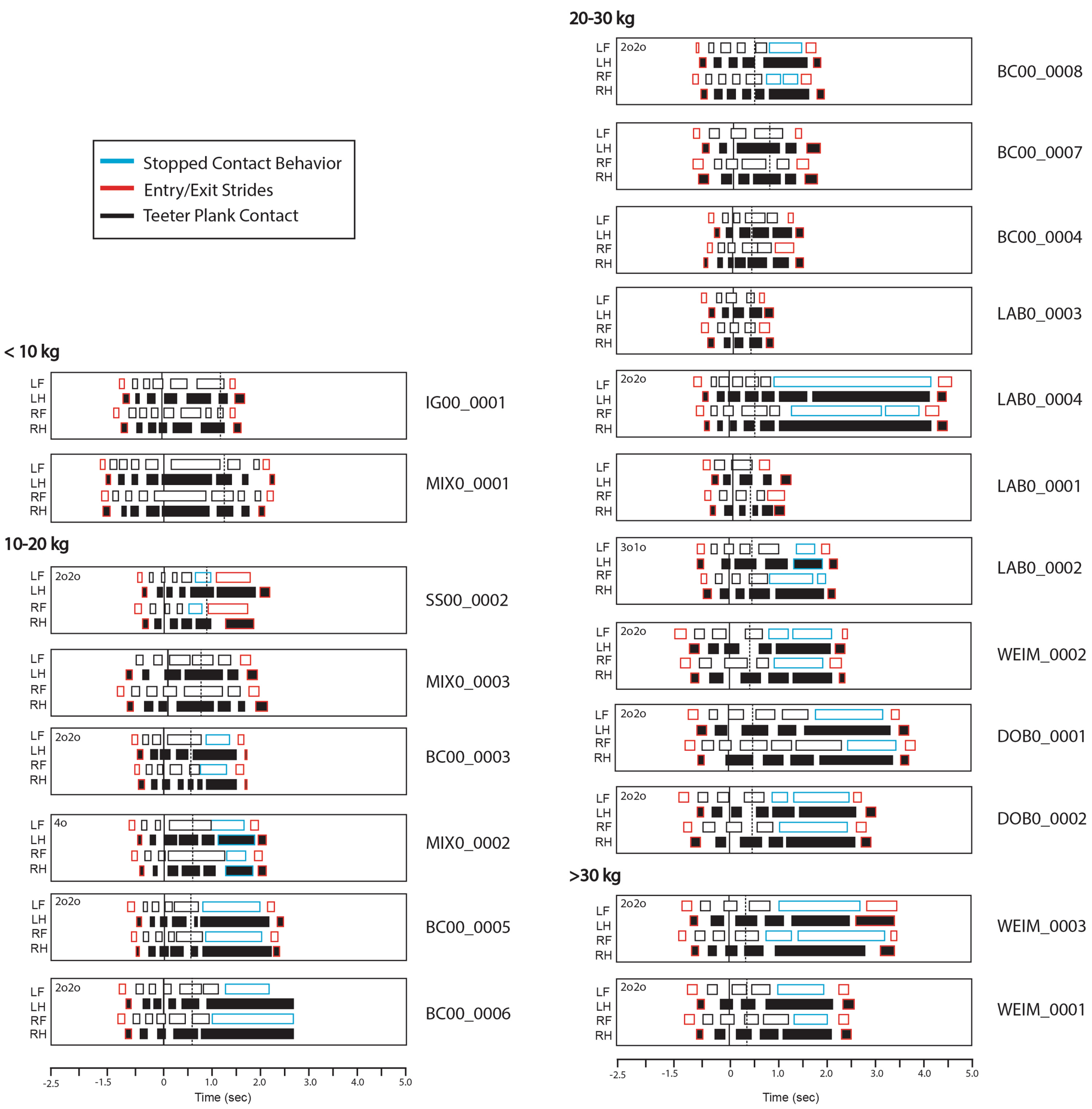

FIGURE 5
Timing, or duty factor, of paw contacts relative to teeter movement phase for each of the 20 dogs. Longer rectangles indicate longer paw contact times. Time = 0 when the teeter starts moving (depicted with a black line). Time of teeter contact with ground is depicted with a dashed line; therefore, the time between these lines is the descent period when the teeter is moving. Front paws are shown in white fill and rear paws are shown in black. Red outlines denote the stride before and stride after the teeter. Blue outlines indicate an observed stopped contact behavior (2o2o, 4o, 3o1o). Dogs are separated by mass category (<10 kg, 10–20 kg, 20–30 kg, >30 kg). BC00_0006 held 2o2o stopped contact on video end.

zone were larger dogs. These variations are likely a direct result of dog stride length, though training may also influence ascent striding.

When comparing the ascent variables between dogs with stopped and not stopped contact behaviors, there were no notable differences. This suggests that dogs may not have differences in preparation for the moving descent of the teeter based on trained contact behavior, though definitive conclusions cannot be made with this small sample size. The footfalls during ascent were generally short in duration relative to the footfalls during descent which may be related to the increased stability of the plank ascent compared to the dynamic movement of the plank descent. One dog appeared to significantly increase contact duration during the last few steps of ascent, potentially anticipating teeter movement (Figure 5: MIX0_001). Fear of teeter movement and the resulting noise on ground contact is a commonly encountered training challenge in dog agility. Future work that addresses the dog's training history would provide insight if there are anticipatory-related effects on performance and if there are differences in obstacle performance in individuals who have had challenges with training compared to those who did not show aversion to movement during training. Variation in ascent performance may also be reflective of the highly variable approach stride and starting

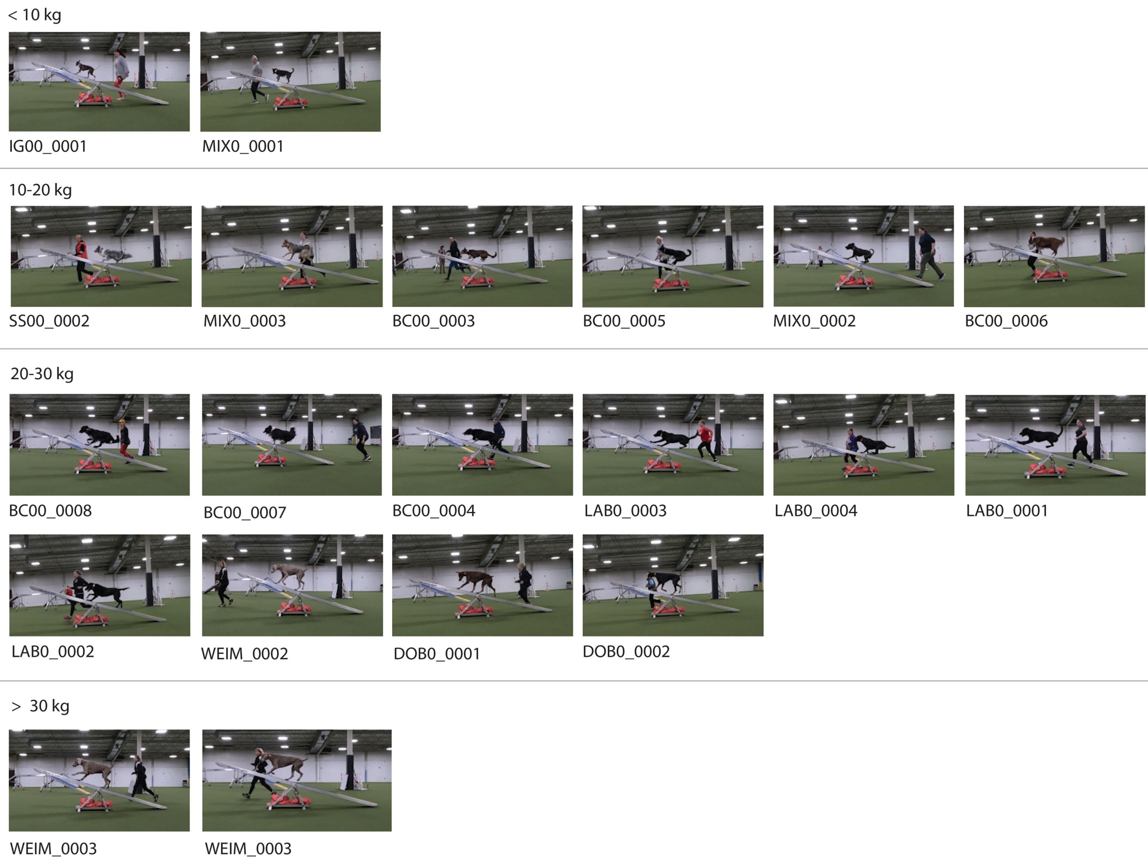

FIGURE 6
Image stills of all 20 dogs at the frame of initial teeter tip.

distance from the teeter. It is unknown how ascent variables may be affected by teeter placement within a course, which obstacle is placed prior to the teeter, the distance between the obstacles, and the line to approach.

4.3 Tip

The location of the dog's torso at the moment of the teeter tip varied substantially. The teeter is a type of lever that consists of a flat surface and a center fulcrum. The force required to drop the teeter must overcome the mass of the portion of the plank in contact with the ground. Mass on the elevated side of the teeter increases the force, causing the teeter to drop. This force is larger with larger mass and when the mass is further from the fulcrum (i.e., longer lever arm). Thus, smaller dogs must move farther out onto the teeter to achieve enough force to overcome the mass of the plank compared to the required distance for larger dogs. Similarly, for dogs equally far away from the fulcrum, larger dogs will exert more force, causing the teeter to drop faster. The smallest dogs appeared to have their whole torso past the tipping point to overcome this inertia. Dogs greater than 10 kilograms often straddled the tipping point. In the larger dogs, some only crossed the tipping point with the head and forelimbs and yet were able to produce enough force to initiate movement.

4.4 Descent

Dogs appeared to use a variety of biomechanical strategies to navigate the moving plank during descent. Some dogs remained in a stationary position past the tipping point of the teeter as the teeter moved, while other dogs moved throughout the movement of the falling teeter. Biomechanical strategies for handling the dynamic movement are likely variable based on a dog's physical characteristics (e.g., height, mass, conformation), balance and coordination, comfort level with movement, and training techniques. Dogs must maintain the coordination needed to compensate for the movement of the obstacle. It is possible that dogs who move through the movement of the teeter have increased balance and coordination, allowing them to compensate for the additional instability and movement. It is also possible that these dogs have more comfort with movement, which could be related to overall temperament or their balance and coordination abilities. Assessing weight shift during movement may be beneficial in further evaluating how dogs handle the movement of the teeter, but weight shift could not be assessed in this study. It is unknown how training contributes to this coordination and comfort with movement. Future work should evaluate correlations with obstacle training strategies as well as relation to a dog's overall balance and coordination ability.

The time of the descent phase was strongly associated with dog mass, with heavier dogs having a faster teeter descent (Figure 8B).

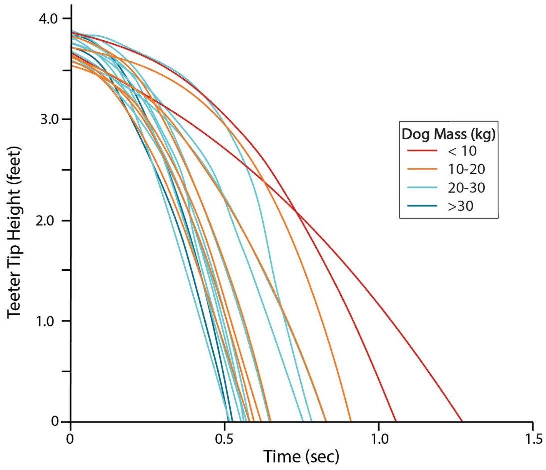

FIGURE 7
Descent of the teeter tip is faster in dogs of higher body mass. Color coding indicates mass categories.

This was not surprising given the physics of the teeter, but it is important to note that teeter drop speed is not equivalent to, or a result of, dog speed. Drop speed is dependent on dog mass and the physics of the lever arm. A faster dog may have a faster overall time to completion due to their ability to get past the fulcrum point faster, but dog speed does not affect the actual rate of descent of the teeter. Also, even with increasing mass, there will be a mechanical limit to the time of descent, due to friction and the design of the teeter, which has speed-limiting, cushioning cylinders on the base to reduce plank whip and rebound (33). In this study, four dogs had teeter descent times less than 0.55 s, but none were less than 0.50 s, suggesting that dogs are approaching the minimum teeter descent time for this teeter. The theoretical limits for the brand of teeter used in this study, which would be tested with a very large weight placed on the very end, is unknown. Observed dog time to descent was generally slower than teeter time to descent, reflecting the lag between the dog's nose passing the fulcrum of the teeter but before mass is applied to the plank (Table 1). The timing of the stride crossing the fulcrum could affect this relationship, as a paw may precede the nose passing the midpoint. Further work to analyze weight distributions at the time of teeter tipping and throughout the descent phase would provide additional data on how dogs utilize their weight to optimize performance.

4.5 Exit

A consistent performance where the dog remains on the teeter until it has contacted the ground, such as using a trained stopped contact behavior, is critical. Failure to successfully perform this obstacle results in a course fault and may potentially result in injury to the dog. The majority of dogs (n = 13, 65%) exhibited a stopped contact behavior with 11 of these 13 being a 2o2o behavior with front feet on the ground and rear feet on the teeter. In this study, 1 dog exhibited a 4o standing behavior with all four paws on the teeter plank after touching the ground. A "3 on 1 off" (3o1o) behavior was exhibited by one dog. Since stopped contact behaviors are trained behaviors, the 3o1o was likely meant to be a 2o2o behavior and was not performed accurately.

This is somewhat consistent with previous research that reported that most dogs had a stopped contact behavior and that the majority of those were 2o2o behaviors (3). However, the actual percentages reported in that study were quite different. The survey by Pechette Markley, et al., reported that almost 90% of dogs had a stopped contact behavior, compared to the 65% in this study (3). Of the dogs in the Pechette Markley et al. survey, 52.7% had 2o2o behavior and 28.7% of the dogs had a 4o standing behavior, compared to 55 and 5%, respectively, in this study (3). The differences between studies may be due to the differences in sample size, with this study having a very small sample size, and population parameters (e.g., breeds, masses, heights, conformations), compared to the survey. It may also be due to the fact that the survey was by handler self-report, rather than observed contact behavior. The differences may also be attributed to the represented breeds in the two studies, as the contact behaviors are likely influenced by the size of the dog. It is also possible that the particular setup for this study influenced the performance behavior and that the contact behaviors noted during this study were not reflective of the dog's normal contact behavior or how the behavior would be cued in other settings.

There was also variation in duration of stopped contact behaviors. Not surprisingly, dogs exhibiting a stopped contact behavior spent more time in contact with the teeter compared to dogs who did not exhibit a stopped behavior. This variation in holding contact behaviors likely depends on specific training techniques as well as the timing of when the handler releases the dog from the behavior. The duration of contact behaviors is also likely to be influenced by the environment. Since speed of agility course completion determines placement ranking, handlers may be more likely to quick release their dogs or not hold the stopped contact behavior for as long of a duration during competition as they do in training. It is unknown how the study environment may have influenced the duty factor on the teeter or stopped contact hold duration. To better evaluate contact behaviors, studies with larger sample sizes and studies evaluating dogs in a more trial-like agility environment are needed.

Dogs with a stopped contact had more footfalls during the exit phase as compared to dogs without a stopped contact. This may be related to the training techniques and contact behaviors that are used to ensure that dogs have at least part of one paw placed in the down contact zone. It is possible that the training techniques used to train a specific contact behavior, as well as the contact behavior itself, cause the dog to be more careful during this phase, thereby resulting in the dog taking more steps to ensure successful contact behavior completion. Interestingly, dogs who performed a stopped contact were faster by all measures except "Time to Dog Exit." We expected dogs preparing for a stopped contact behavior would result in a slower performance of the obstacle. However, they were only slower when the time holding the contact behavior was included. Overall, the total obstacle completion time was generally similar between dogs with stopped contacts and those without. This suggests that a quick-release version of stopped contact behavior commonly observed during competitions is comparable

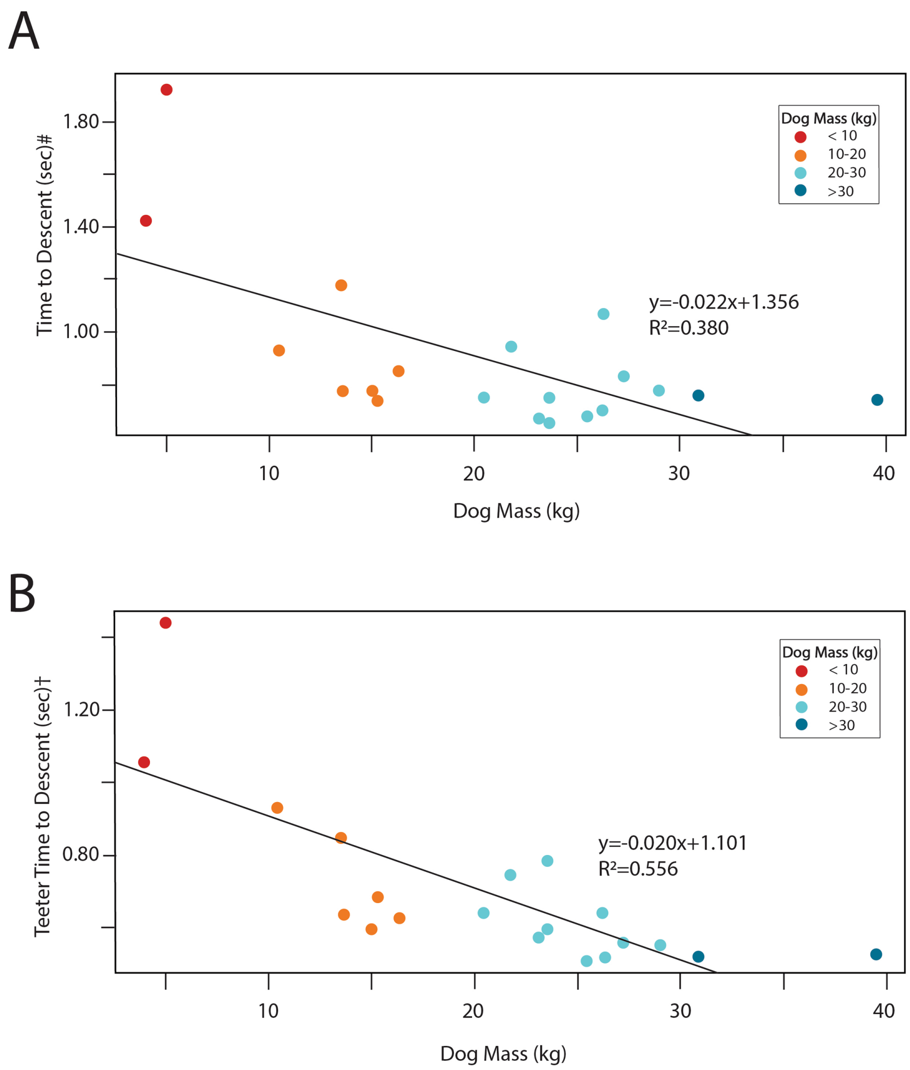

FIGURE 8
Scatterplots with superimposed linear regression line showing the association between dog mass and **(A)** dog time to descent# (p = 0.002), and **(B)** teeter time to descent† (p < 0.001). Color coding indicates mass categories.

to, if not faster than, a non-stopped contact behavior for the teeter obstacle.

Exit strides were also highly variable between dogs. Some of this variability appears to be related to contact behavior, with dogs who had a 2o2o stopped contact placing their paws further from the edge of the teeter plank. As this study focused on single obstacle performance, there was not a specified next obstacle to recreate an exit as seen during competition settings, therefore this behavior was not quantified. Future work looking at teeter performance within courses would provide more insights to variability in entry and exits to the teeter.

4.6 Limitations and conclusion

Limitations for this study include a sample size of 20 dogs. While there was a wide variety of breeds and body weights, the sample did not necessarily reflect the most common agility breed distribution, nor did it reflect the within-breed variation seen in many of the popular agility breeds, such as Border Collies. In previous studies, the most common breeds competing in agility were Border Collie, followed by mixed-breed, Shetland Sheepdog, and Australian Shepherd (3). While Border Collies were the most common breed in this study, Labrador Retrievers and Weimaraners were overrepresented compared to the general agility population data.

Because of the small sample size, it was not possible to look at correlations between footfall patterns and performance variables with dog size other than mass (e.g., height, other conformation), or specific training techniques. Since this was an experimental setup, the dog's performance may also not be a true reflection of the dog's performance in training or competition. It is possible that performance variables may differ substantially when the teeter is performed in a full course setting at speed. With this particular experimental setup, it was also not possible to evaluate how different approach angles and prior obstacle types and orientations affect teeter performance.

Another limitation is that only a single teeter brand was used in this study. While teeters must meet agility organization specifications, there is still variability in teeter design and specifications between manufacturers and even between different lines within the same manufacturer. For more comprehensive evaluation of performance variables, obstacles from multiple manufacturers should be compared. Another limitation was that no veterinary examination was performed so inclusion relied on the handler reporting that their dog was injury-free. Because handlers may not always be able to identify that their dog has a mild injury, some dogs participating in this study could have had an injury or underlying orthopedic disease that could influence performance variables. Injury history data was also not acquired, and previous injury could also influence obstacle performance.

These data suggest that dogs of different sizes use different biomechanical strategies to perform a dynamic obstacle and that variability in contact behavior results in variation in performance strategies. Results of this study provide insight into teeter performance strategies and variables that can be utilized for evaluation in future biomechanical studies. This study also provides initial data on biomechanical strategies used by dogs on dynamic surfaces, which may offer insight into dynamic stability and postural control in dogs and how that influences injury occurrence during sport. Future studies should recruit a larger number and variety of dogs, making sure to include the most common agility breeds, and a variety of body morphologies within the breeds. Given the notable differences in performance we observed between the smallest and largest dogs, future studies should carefully consider dog size. Future studies should also include more repetitions, camera angles that ensure all data is captured, and should be validated against videos of dogs in a training and competition setting. Future data capturing kinematics and kinetics throughout the performance phases would provide more robust data for clinical and performance correlations. Analysis of the performance of different brands of teeters with specific weights placed at known distances from the fulcrum would provide insight into obstacle variability and allow for theoretical models of optimal dog performance. Collecting details on training history and injury history in a larger population of dogs may allow for correlation between performance variables, training techniques and injury. Results of this study provide foundational context to future biomechanical studies of canines on dynamic surfaces, which may offer insight into sport injury development and prevention.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The animal studies were approved by The Ohio State University's institutional animal care and use committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

AP: Funding acquisition, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing. MW: Data curation, Investigation, Methodology, Resources, Software, Writing – original draft, Writing – review & editing. AS: Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. RO: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This study was funded by the American Kennel Club Canine Health Foundation (Grant #03068-A) and startup funds to RAO from the University of Akron.

Acknowledgments

We would like to thank C. Ramey, B. Seitz, R. Depp, A. Szilvas, J. Gibson, and M. Moore Jackson for assistance with data collection. We would like to thank Jennifer Crank for the use of the IncrediPAWS facility and equipment for data collection, and the handlers and dogs for participation in this study.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2024.1492391/full#supplementary-material

References

1. De Young C. Personal communication. (2024).

2. Regulations for agility trials and agility course test (ACT). (2024). Available at: https://images.akc.org/pdf/rulebooks/REAGIL.pdf

3. Pechette Markley A, Shoben AB, Kieves NR. Internet survey of risk factors associated with training and competition in dogs competing in agility competitions. *Front Vet Sci*. (2021) 8:791617. doi: 10.3389/fvets.2021.791617

4. Pechette Markley A, Shoben AB, Kieves NR. Internet-based survey of the frequency and types of orthopedic conditions and injuries experienced by dogs competing in agility. *J Am Vet Med Assoc*. (2021) 259:1001–8. doi: 10.2460/javma.259.9.1001

5. Sundby AE, Pechette Markley A, Shoben AB, Kieves NR. Internet survey evaluation of demographic risk factors for injury in canine agility athletes. *Front Vet Sci*. (2022) 9:869702. doi: 10.3389/fvets.2022.869702

6. Evanow JA, VanDeventer G, Dinallo G, Mann S, Frye CW, Wakshlag JJ. Internet survey of participant demographics and risk factors for injury in competitive agility dogs. *VCOT Open*. (2021) 4:e92–8. doi: 10.1055/s-0041-1735843

7. Inkilä L, Hyytiäinen HK, Hielm-Björkman A, Junnila J, Bergh A, Boström A. Part II of Finnish agility dog survey: agility-related injuries and risk factors for injury in competition-level agility dogs. *Animals*. (2022) 12:227. doi: 10.3390/ani12030227

8. Cullen KL, Dickey JP, Bent LR, Thomason JJ, Moëns NMM. Survey-based analysis of risk factors for injury among dogs participating in agility training and competition events. *J Am Vet Med Assoc*. (2013) 243:1019–24. doi: 10.2460/javma.243.7.1019

9. Sellon DC, Martucci K, Wenz JR, Marcellin-Little DJ, Powers M, Cullen KL. A survey of risk factors for digit injuries among dogs training and competing in agility events. *J Am Vet Med Assoc*. (2018) 252:75–83. doi: 10.2460/javma.252.1.75

10. Sellon DC, Marcellin-Little DJ. Risk factors for cranial cruciate ligament rupture in dogs participating in canine agility. *BMC Vet Res*. (2022) 18:39. doi: 10.1186/s12917-022-03146-2

11. Brachman A, Kamieniarz A, Michalska J, Pawłowski M, Słomka KJ, Juras G. Balance training programs in athletes - a systematic review. *J Hum Kinet*. (2017) 58:45–64. doi: 10.1515/hukin-2017-0088

12. Cullen KL, Dickey JP, Bent LR, Thomason JJ, Moëns NMM. Internet-based survey of the nature and perceived causes of injury to dogs participating in agility training and competition events. *J Am Vet Med Assoc*. (2013) 243:1010–8. doi: 10.2460/javma.243.7.1010

13. Pogue J, Zink C, Kieves NR. Effects of jump height on forelimb landing forces in border collies. *Front Vet Sci*. (2022) 9:1006990. doi: 10.3389/fvets.2022.1006990

14. Blake S, de Godoy RF. Kinematics and kinetics of dogs completing jump and A-frame exercises. *Comp Exerc Physiol*. (2021) 17:351–66. doi: 10.3920/CEP200067

15. Alcock J, Birch E, Boyd J. Effect of jumping style on the performance of large and medium elite agility dogs. *Comp Exerc Physiol*. (2015) 11:145–50. doi: 10.3920/CEP150017

16. Williams JM, Jackson R, Phillips C, Wills AP. The effect of the A-frame on forelimb kinematics in experienced and inexperienced agility dogs. *Comp Exerc Physiol*. (2017) 13:243–9. doi: 10.3920/CEP170014

17. Appelgrein C, Glyde MR, Hosgood G, Dempsey AR, Wickham S. Reduction of the A-frame angle of incline does not change the maximum carpal joint extension angle in agility dogs entering the A-frame. *Vet Comp Orthop Traumatol*. (2018) 31:77–82. doi: 10.3415/VCOT-17-04-0049

18. Appelgrein C, Glyde MR, Hosgood G, Dempsey AR, Wickham S. Kinetic gait analysis of agility dogs entering the A-frame. *Vet Comp Orthop Traumatol*. (2019) 32:97–103. doi: 10.1055/s-0038-1677492

19. Castilla A, Knotek B, Vitt M, Gordon-Evans W. Carpal extension angles in agility dogs exiting the A-frame and hurdle jumps. *Vet Comp Orthop Traumatol*. (2020) 33:142–6. doi: 10.1055/s-0039-3400484

20. Birch E, Carter A, Boyd J. An examination of jump kinematics in dogs over increasing hurdle heights. *Comp Exerc Physiol*. (2016) 12:91–8. doi: 10.3920/CEP150037

21. Birch E, Boyd J, Doyle G, Pullen A. Small and medium agility dogs alter their kinematics when the distance between hurdles differs. *Comp Exerc Physiol*. (2015) 11:75–8. doi: 10.3920/CEP150015

22. Pfau T, Garland de Rivaz A, Brighton S, Weller R. Kinetics of jump landing in agility dogs. *Vet J*. (2011) 190:278–83. doi: 10.1016/j.tvjl.2010.10.008

23. Birch E, Leśniak K. Effect of fence height on joint angles of agility dogs. *Vet J*. (2013) 198:e99–e102. doi: 10.1016/j.tvjl.2013.09.041

24. Birch E, Boyd J, Doyle G, Pullen A. The effects of altered distances between obstacles on the jump kinematics and apparent joint angulations of large agility dogs. *Vet J*. (2015) 204:174–8. doi: 10.1016/j.tvjl.2015.02.019

25. Söhnel K, Rode C, de Lussanet MHE, Wagner H, Fischer MS, Andrada E. Limb dynamics in agility jumps of beginner and advanced dogs. *J Exp Biol*. (2020) 223:jeb202119. doi: 10.1242/jeb.202119

26. Söhnel K, Andrada E, de Lussanet MHE, Wagner H, Fischer MS, Rode C. Single limb dynamics of jumping turns in dogs. *Res Vet Sci*. (2021) 140:69–78. doi: 10.1016/j.rvsc.2021.08.003

27. Eicher LD, Markley AP, Shoben A, Sundby AE, Kieves NR. Evaluation of variability in gait styles used by dogs completing weave poles in agility competition and its effect on completion of the obstacle. *Front Vet Sci*. (2021) 8:761493. doi: 10.3389/fvets.2021.761493

28. DiMichele JK, Pechette Markley A, Shoben A, Kieves NR. Evaluation of variability in performance and paw placement patterns by dogs completing the dog walk obstacle in an agility competition. *PLoS One*. (2024) 19:e0299592. doi: 10.1371/journal.pone.0299592

29. Lutonsky C, Peham C, Mucha M, Reicher B, Gaspar R, Tichy A, et al. External mechanical perturbations challenge postural stability in dogs. *Front Vet Sci*. (2023) 10:1249951. doi: 10.3389/fvets.2023.1249951

30. Vero AM, Wagner G, Lobaton E, Russell K, Olby N. Age-related changes in posture steadiness in the companion dog. *Innov Aging*. (2021) 5:959–60. doi: 10.1093/geroni/igab046.3461

31. Lee S, Lee J-M, Park H, Cha Y, Cheong J. Validity of the wii balance board for evaluation of medial patellar luxation in small sized dog. *J Vet Clin*. (2019) 36:297–300. doi: 10.17555/jvc.2019.12.36.6.297

32. Lee S, Lee J-M, Park H, Cha Y, Cheong J. Balance evaluation after reconstruction of medial patellar luxation in small-sized dogs with Wii balance board. *J Vet Clin*. (2019) 36:301–5. doi: 10.17555/jvc.2019.12.36.6.301

33. Clip and Go Seesaw. Available at: https://clipandgoagility.com/clip-and-go-seesaw/

frontiers | Frontiers in Veterinary Science

TYPE Original Research
PUBLISHED 06 December 2024
DOI 10.3389/fvets.2024.1473977

Check for updates

OPEN ACCESS

EDITED BY
Scott Talpey,
La Trobe University, Australia

REVIEWED BY
Olga Witkowska-Pilaszewicz,
Warsaw University of Life Sciences, Poland
Matthew Warren Brunke,
Veterinary Referral Associates, Gaithersburg, MD, United States

*CORRESPONDENCE
Debra C. Sellon
✉ dsellon@wsu.edu

†PRESENT ADDRESS
Arielle Pechette Markley,
Red Sage Integrative Veterinary Partners,
Fort Collins, CO, United States

RECEIVED 31 July 2024
ACCEPTED 11 November 2024
PUBLISHED 06 December 2024

CITATION
Sellon DC, Shoben A, Pechette Markley A, McFarlane D and Marcellin-Little DJ (2024) Development of a web-based tool to assess daily rating of perceived exertion in agility dogs.
Front. Vet. Sci. 11:1473977.
doi: 10.3389/fvets.2024.1473977

Development of a web-based tool to assess daily rating of perceived exertion in agility dogs

Debra C. Sellon[1]*, Abigail Shoben[2], Arielle Pechette Markley[3†], Dianne McFarlane[4] and Denis J. Marcellin-Little[5]

[1]Department of Veterinary Clinical Sciences, College of Veterinary Medicine, Washington State University, Pullman, WA, United States, [2]Division of Biostatistics, College of Public Health, The Ohio State University, Columbus, OH, United States, [3]Department of Veterinary Clinical Sciences, College of Veterinary Medicine, The Ohio State University, Columbus, OH, United States, [4]Department of Large Animal Clinical Sciences, College of Veterinary Medicine, University of Florida, Gainesville, FL, United States, [5]Department of Surgical and Radiological Sciences, School of Veterinary Medicine, University of California, Davis, Davis, CA, United States

Objective: To develop a web-based tool for daily use by agility handlers to log rating of perceived exertion (RPE) for dogs as an aid in quantifying daily exercise and training load and to improve training and conditioning strategies.

Procedures: Focus group meetings with small groups of handlers were conducted via internet—based video conferencing using a semi-structured interview format. Meeting notes were coded for reflexive thematic analysis. The RPE logging tool was revised based on handler feedback. Each handler was asked to log their dog's daily RPE data for 1 week. Data were analyzed to assess compliance and timeliness of entries. Participants completed a post-logging questionnaire to provide feedback about their experiences.

Results: Eighteen agility dog handlers participated in all phases of the project. Handler and dog demographics were similar to previously reported demographics of agility participants in the United States. Reflexive thematic analysis of their comments related to the initial draft RPE logging tool yielded 3 initial themes, all of which supported a fourth and major theme: the need for specific and detailed training resources before agility handlers utilized the RPE tool. Of 18 handlers, 14 (78%) submitted logging records for the full week. Median time for data entry was 87 s (IQR = 56–117 s), and 92% of logging records were entered within 1 day of the events which were being recorded. In the follow-up questionnaire the handlers did not identify any major concerns. Based on all available data from the handlers, a final version of the RPE logging tool was produced.

Conclusion and clinical relevance: Agility dog handlers are very interested in developing and validating tools to quantify training load for their dogs. The final RPE logging tool was quick and easy to use. Further validation of this logging tool is required with a larger number of handlers and comparison to physiologic data from exercising dogs.

KEYWORDS

agility, dog, rating of perceived exertion, sports medicine, training load

Introduction

Canine agility is growing in popularity, with a concomitant increase in interest in evidence-based practices that support optimal athletic performance and competitive longevity. The sport of agility is physically demanding because it combines running, jumping obstacles, frequent abrupt turns at speed, navigation of elevated and angled frames or teeter-totters, and weaving between tightly spaced poles. Retrospective studies of agility dog injuries based on handler reports estimate that one-third or more of agility dogs experience one or more injuries in their competitive career, with one-third of those dogs having more than one injury (1–8). The most common anatomic sites reported to be injured are the shoulder, back, neck, and digits (2–6, 9, 10).

A recent survey of more than 1,300 agility handlers ranked the relative importance of 12 research areas related to canine agility (10). The highest ranked research priorities were enhancing and prolonging the athletic lifespan for dogs, identifying risk factors for specific types of injuries, physical conditioning programs, rehabilitation programs for injured dogs, improving safety of equipment and course design, and understanding safety of various surfaces used of agility training and competition. Each of these areas of research would benefit from the ability to collect data related to canine training and activity load in an accurate, efficient, and prospective manner.

Training and competition load in human athletes refers to the total volume, intensity, and type of physical activity undertaken by the athlete over a period of time (11). This concept includes both external training load, what the athlete does, and internal training load, the psychobiological responses to these activities (11). The internal training load experienced as a result of the work performed (external training load) can change according to fitness status of the athlete. External load (the physical work executed) and internal load (the biological response) can now be simultaneously measured in many ways in human athletes such as Global Positioning System (GPS) monitoring combined with heart rate monitors (12). Training and competition load stimulates adaptation of body systems which can result in increased fitness and improved performance. There are currently no validated tools to measure daily athletic activities and "training load" of agility dogs. There are only a few reports of potential links between activity, conditioning, or training practices and risk of injury in agility dogs (3, 13). In contrast, there is an abundance of information on this topic related to human athletes in a wide variety of sports (14–17) and load management has emerged as an important factor in injury risk (14). Objective exercise data are also used to study factors predisposing racing horses to injury (18, 19).

Training or sport exposure can be recorded in a variety of ways, including daily training logs, activity monitoring with electronic devices, recording of specific event frequencies and durations, and self-report ratings of perceived exertion (20). The rating of perceived exertion (RPE) as reported by the athlete after each training session was first described by Borg (21). This simple, subjective measure has been modified in numerous ways to fit athletes in multiple sports (15–17, 22–24). Despite its simplicity, the RPE and its modifications have often been more valuable in monitoring training load than objective parameters such as training days, training volume, or repetitions of individual training events. The RPE has been validated for many sports and activities, and it does not require any technology for implementation.

Assessments of RPE in children performing treadmill exercise, provided by trained external observers, corresponded with objective measures of exercise intensity and with the self-rating provided by the children (25, 26). A perceived exertion scale (0 to 4) has been described for dogs exercising on a treadmill; observer scores correlated well with objective physiologic measures (27). An RPE of 1 to 10 as assessed by trainers and riders correlated with physiologic variables of exercise intensity during race horse training sessions (28). Given that self-reported measures of training exposure are considered generally accurate for human athletes (29, 30), and that external observers provide valid ratings of exertion for children, dogs, and horses, it is reasonable to expect that handler-reported RPE would be valid as an aid in assessing training and activity load for agility dogs. The goals of this project were to develop a concise, easy-to-use RPE tool to aid in quantifying daily exercise and training load in dogs and to test its performance in a small group of agility handlers.

Materials and methods

Participants

Participants, referred to as "handlers" in this report, were recruited through advertisement on social media sites that targeted active agility competitors in the United States. Handlers were required to be 18 years of age or older, reside in the United States, and be currently competing (within the past 3 months) in agility with one dog or more. Handler participants were asked to complete 5 activities; (1) respond to an online enrollment questionnaire; (2) review background information introducing the concept of RPE and a draft RPE instrument for agility dogs; (3) participate in an online virtual focus group session in a semi-structured interview format; (4) use a revised draft RPE tool for 1 week; and (5) complete an online questionnaire to provide feedback about their RPE logging experience. The Institutional Review Board of Washington State University determined this project satisfied the criteria for exempt research. Anonymized survey responses and datasets generated and/or analyzed for this report are available upon reasonable request to the authors.

Enrollment questionnaire

An internet-based questionnaire for handlers was designed on a commercial internet survey site (Qualtrics, Provo, UT).[1] The enrollment questionnaire was adapted from previous surveys of agility handlers and consisted of 3 sections; (1) determination of eligibility for participation; (2) demographic and agility-related information about the specific dog nominated for participation; and (3) demographic information about the handler. Full text of the enrollment questionnaire is available as Supplementary Item 1.

Section 2 of the enrollment questionnaire sought to determine dog-related information including signalment (age, sex, breed), body characteristics (weight, body condition, height in inches measured at the withers), and prior involvement and experiences in agility.

1 www.qualtrics.com

Agility-related questions included most frequent competition venue, highest level of agility, approximate average speed in yards per second (yps), experience at a national championship event, most common jump height, access to training facilities, and anticipated approximate number of days of competition in the next year.

Handler-related information collected in section 3 included number of dogs currently competing or training to compete in agility, number of dogs with which the handler has competed in agility over their lifetime, number of years the handler has been active in agility, types of participation in agility, medical education or training, age, and gender.

Draft RPE logging tool

An initial draft of a daily RPE tool was prepared by consensus collaboration of the authors (Figure 1). The draft RPE was designed with the goal of optimizing quality of data collected from the participating handlers while maintaining ease of use and minimizing daily time requirements. This logging tool was developed using the same commercial internet survey site used for the enrollment questionnaire. The draft logging tool began with a section containing 3 questions intended to establish and confirm participant identification (handler name, dog name, and personal identification number [PIN]).

The main portion of the daily RPE tool contained 7 questions related to the activities of the dog on that date. Respondents were asked whether they had participated in any agility training and/or competition activities. Training or competition time was defined as the time spent training or performing in any activities related to agility, with or without using specific agility equipment or obstacles. If the respondent indicated they had participated in agility activities, they were asked to estimate the time in minutes for all agility-related activities on that date. The next question asked the handler to provide an overall RPE for all agility activities on that date in which a rating of 1 indicated no exertion at all and a rating of 10 indicated the maximal possible exertion. This was followed by a request for a separate RPE that represented the maximum RPE that occurred at any single point in time on that date. The respondent was next asked whether their dog had participated in non-agility related physical activities on that date. A list of various types of physical activities, adapted from a previous agility-related survey, was provided followed by a free text response box in which other activities or explanations could be provided. The final question asked the handler to provide an estimate of the total RPE for the dog for all activities (agility and non-agility) for that date with a rating of 1 indicating no exertion at all and a rating of 10 indicating the maximal possible exertion for the day.

Focus groups (semi-structured interviews)

Five structured interviews were conducted using internet-based video conferencing software (Zoom Video Communications, Inc)[2] with a maximum of 7 participants in any one session. Prior to the meeting, participants were provided with an opportunity to review the initial draft RPE logging tool. Each meeting was conducted using a detailed script with visual aids which were presented using shared screen technology. Meetings began with a review of background information, project personnel, funding, goals, eligibility criteria, methods, anticipated time commitment, and a statement of risks and benefits for participants. Participants were asked to respond to questions related to the enrollment questionnaire, which was completed by each handler prior to the focus group sessions, and the clarity of questions within the draft daily RPE logging tool. Sessions were not recorded; detailed notes of the discussion were chronicled by the investigators.

Data from the focus group interviews were analyzed using the six-phase process of reflexive thematic analysis (RTA), as described by Braun and Clarke (31). The underlying research goal for this analysis was to identify possible modifications to the daily RPE logging tool that would make it more understandable and usable by an average agility handler. Because focus group discussions were not recorded, initial coding of data was based on the investigator's contemporaneous notes. Each note was individually assigned one or more content codes. Related codes were grouped into themes and subthemes through an iterative process. After review, themes and subthemes were used to form a thematic "map" of the analysis. Themes were ultimately defined and named. Final themes were reviewed by the research team as a whole, which included individuals with deep knowledge of agility and others with more superficial knowledge. On the basis of this analysis, a revised draft RPE logging tool was prepared.

RPE logging

After the focus group sessions, handlers were asked to log their dog's activities using the revised draft RPE logging tool daily for at least 7 days. An automated email reminder containing a link to the logging tool was sent to each participating handler at 12 pm (noon) Pacific standard time each day between 12/6/2023 and 12/14/2023. Date and time of data entry by each handler was automatically recorded by the survey software (date of entry). This date of entry was compared to the date of the activity which the handler indicated at the beginning of each record.

Follow-up questionnaire

After logging was complete, participants were asked to complete an online questionnaire designed by the research team using the same commercial internet survey site used for enrollment and daily logging questionnaires. This questionnaire included 16 questions, most of which were open-ended. A summary of questions is shown in Figure 2 and full text of this questionnaire is available as Supplementary Item 2.

Results

Enrollment questionnaire

Between 10/18/2023 and 10/26/2023, 45 individuals accessed the online enrollment questionnaire. Twelve respondents (27%) did not provide personal contact information and were excluded from

2 www.zoom.us

Questions in Initial Draft RPE Survey

Respondent Identification

- What is your dog's name?
- What is the unique identification number that you designated for this study?
- For what date are you providing information?

Agility Activities

- Did you and your dog engage in any agility training or competition activities today?
- What is your estimate of the approximate time in minutes that your dog spent in active agility training or competition activities today?
- For today, what is your overall rating of perceived exertion for your dog in agility training and/or competition activities on this day? For this question, consider the RPE for all agility activities throughout the day.
- For today, what is the maximum rating of perceived exertion that occurred for your dog when engaged in agility training and/or competition activities? For this question, consider the maximum RPE achieved at any single point in the day?

Non-agility Activities

- Did your dog participate in any of the following non-agility activities today? Check all that apply.
- Please provide a brief description of any other non-agility physical activities, not listed above, which your dog did today ,and any other explanatory comments related to today's activities.
- For today, what is your overall rating of perceived exertion for your dog for all physical activities throughout the day?

FIGURE 1
Draft RPE logging tool as initially prepared by the research team. These questions were shared with focus group participants and discussed in semi-structured interview format.

participation. For the remaining 33 respondents, median time for questionnaire completion was 531 s (IQR = 391–732 s). These respondents were contacted via email and provided with a list of available times for focus group discussions. Of these 33 handlers, 18 were able to schedule and participate in a focus group discussion scheduled between 10/26/2023 and 11/1/2023 (Table 1).

Enrollment questionnaires of the 18 handlers who participated in a focus group discussion were further reviewed. These handlers were from 12 states. Six individuals were from Washington State, two from New York and one each from Arkansas, California, Florida, Idaho, Kentucky, Oklahoma, Oregon, Pennsylvania, Tennessee, and Virginia. Of the 17 handlers who reported their age, similar numbers of respondents were between 18 and 40 years of age ($n = 8$, 47%) and greater than 41 years of age ($n = 9$, 53%). Nearly all handlers (17/18, 94%) indicated that they were female. The number of dogs owned by each handler varied with 6 handlers (33%) owning only 1 dog, 5 handlers (28%) owning 2 dogs, 6 handlers (33%) owning 3 dogs, and 1 handler (6%) owning 4 or more dogs. Years of experience in agility varied from <3 years (4 handlers, 22%) to >15 years (4 handlers, 22%).

Ten handlers (56%) had competed in at least one national agility competition within the past 5 years. Of the 18 enrolled handlers, the preferred agility competition venue was American Kennel Club for 9 handlers (50%), Canine Performance Events for 4 handlers (22%), North American Dog Agility Council for 2 handlers (11%), United Kingdom Agility International for 2 handlers (11%), and United State Dog Agility Association for 1 handler (6%). Handlers indicated that their most common type of agility training was either regular in-person group classes with an instructor (12 handlers, 67%) or training alone at their own home or premises (5 handlers, 28%). One handler indicated that they primarily trained alone at a premises owned by another person.

There were 12 breeds of dogs represented including 5 border collies, 2 Australian shepherds, 2 Doberman pinschers, and 1 each of 9 other breeds. Mean body weight for enrolled dogs was 19 ± 8 kg (41 ± 18.4 lbs). Mean height at the withers for enrolled dogs was 19.2 ± 5.0 inches. Competition jump heights varied from 8 inches (4 dogs, 22.2%) to 24 inches (2 dogs, 11.1%) with the largest number of dogs jumping 20 inches (8 dogs, 44.4%). The highest level of competition achieved by enrolled dogs ranged from Starters/Novice/Beginner (5 dogs, 27.8%) to Masters/Elite/Excellent (11 dogs, 61.1%).

Reflexive thematic analysis

Data from focus group interviews were separated into 61 comments or questions derived from the investigators' contemporaneous notes. Comments unrelated to the central research goal of identifying necessary modifications or clarifications to the daily RPE logging tool were excluded ($n = 12$). The remaining 49 comments and suggestions were collated into 4 themes each of which comprised two or more sub-themes (Figure 3). The most compelling theme identified was the need to modify and clarify the underlying

Questions in Follow-Up Questionnaire

Respondent Identification

- What is the name of the dog for which you were entering data in the daily logging survey?

Follow-up Questions

- Rate the ease of use of the daily logging survey on a scale of 1 (very easy) to 10 (very difficult).
- Approximately how long in minutes did it take you to complete the survey each day?
- When did you most commonly input the responses for your dog?
- Do you have any comments about the time of day you typically found it most convenient or best to provide your RPE logging data?
- Were the daily email reminders helpful to you?
- Do you have any additional comments about the email reminders? These reminders were sent at 12 pm (noon) Pacific time. Was this a reasonable time for the reminders to do you have another suggestion?
- Do you feel that you were able to provide a reasonably accurate rating of perceived exertion for your dog for agility-related activities on each day?
- Do you have suggestions for other non-agility activities that should be added to the list that is currently used in the RPE logging survey?
- Do you feel that you were able to provide a reasonably accurate rating of perceived exertion for your dog for all physical activities on each day?
- Do you feel that you modified your daily interactions with your dog in any way because of the anticipation of providing RPE ratings on that day?
- Please provide comments or explanations about how the use of the daily RPE logging survey may have impacted your daily interactions with your dog.
- The questions on the effect of weather on your dog's exertion and amount of mental or emotional exertion/stress/stimulation your dog experienced were added to the daily RPE survey based on suggestions from Phase 1 participants. What was your reaction to those questions? Do you feel they were helpful? Were they relatively easy for you to answer?
- Are there specific changes to the daily RPE logging survey that you feel should be made prior to more widespread use of the daily survey in Phase 2 of this project?
- Do you have additional comments about the daily RPE logging survey you would like to provide? Do you think this project is ready to move forward into Phase 2? Would you recommend Phase 2 participation to your friends and acquaintances?
- Would you like the opportunity to have a Zoom meeting with representatives from the research team to discuss your experiences further?

FIGURE 2
Questions included in the follow-up questionnaire for 18 handlers who provided daily RPE logging records of their dogs' daily activities.

TABLE 1 Focus group dates and participants for discussions of the initial draft of a daily rate of perceived exertion tool.

Focus group number	Date	Handler participants	Project personnel participants
1	10/30/2023	7	3
2	11/6/2023	3	1
3	11/8/2023	2	1
4	11/14/2023	5	1
5	11/16/2023	1	1

definitions and utilization of the RPE scales. Several handlers were confused by the distinctions between the two RPE scales related to agility activities. One scale attempted to quantify the maximum agility-related exertion experienced at any single point in time on a given day; the second scale attempted to quantify the overall or cumulative level of agility-related exertion experienced by the dog on that day. Other comments requested visual or verbal descriptors on the sliding scale to assist them in conceptualizing the level of exertion associated with each number. The second theme identified in the analysis related to modifications to the list of non-agility activities in which the dogs might participate on any given day. The concerns primarily related to definitions of running, playing, hiking, and walking. There were also requests for clarification of the definitions of core strengthening and balance training and trick training. The third theme related to the ways in which weather conditions and mental stress might impact total exertion by the dog on any given day. These three themes were strongly related to the fourth theme: the need for detailed and readily available training resources. The suggestion of a training video was strongly supported, with requests that such a video

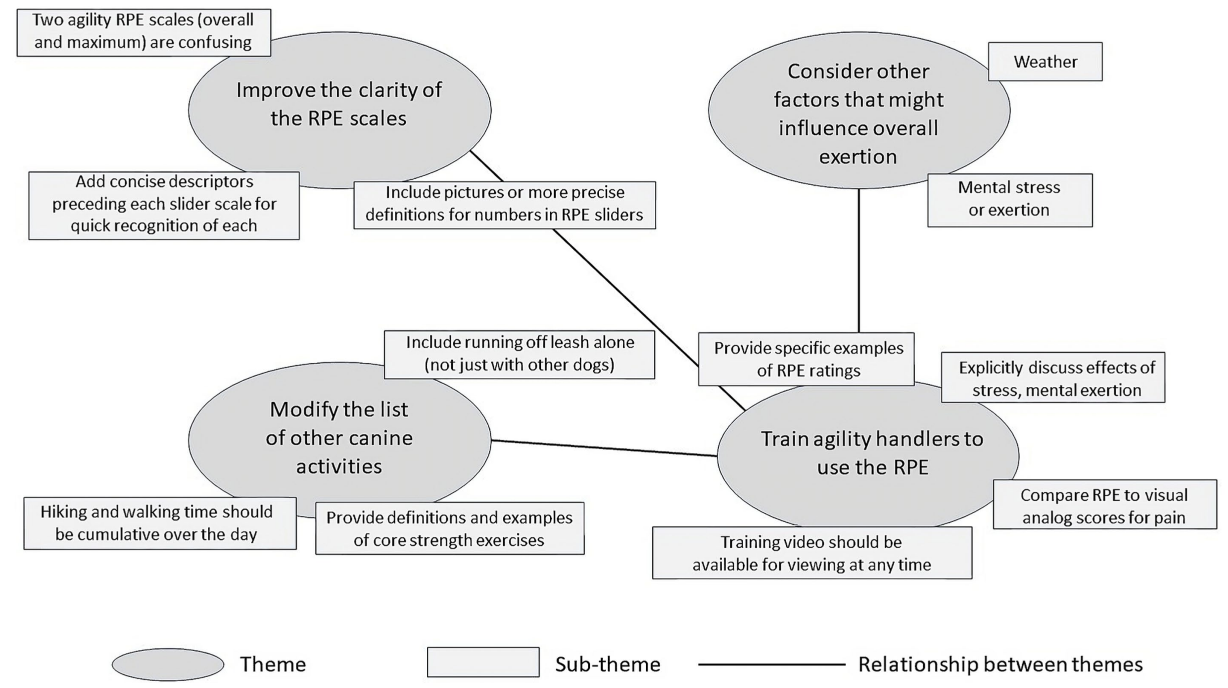

FIGURE 3
Thematic map including themes, sub-themes, and relationship between themes developed using reflexive thematic analysis of data from semi-structured interviews conducted in electronic focus group discussions related to the structure, function, and clarity of the draft RPE logging tool shown in Figure 1.

include specific examples and clear definitions. There was a strong consensus that the training video should be available online so that it could be watched independently and supplemented by a mechanism to ask questions as needed.

Revision of the RPE logging tool

After review and analysis of focus group discussions, the RPE logging tool was revised. The agility-related portion of the logging tool was revised to comprise only a single daily RPE for all agility-related activities. An indication of how much the weather conditions might have affected exertion for the dog on that date (none at all, a little, a moderate amount, a lot, a great deal) was added. A question related to mental or emotional exertion, stress, or stimulation was also added. Mental exertion was defined as sustained and prolonged cognitive (brain or mental) activity. Emotional exertion or stress was defined as a state of worry or mental tension caused by a difficult situation. Handlers provided a rating of mental or emotional stress or exertion on a scale in which 1 indicated no mental or emotional stress or exertion at all and 10 indicated the maximal possible mental and emotional exertion. The questions included in the revised RPE logging tool are shown in Figure 4.

RPE logging

Between 12/6/2023 and 12/14/2023, handlers logged daily activities using the revised RPE logging tool. The number of days for which activity reports were logged for each dog/handler ranged from 4 to 8 days (mean = 6.9 days) for a total of 125 daily logging records. Of the 18 handlers, 14 (78%) submitted logging records for the requested 7 or 8 days. Median data entry time was 87 s (IQR = 56–117 s). Of the 125 logging records, one record had an incorrect date that indicated the information provided was for a date 4 days in the future. Of the remaining 124 logging records, 96 (77%) were entered on the day the activities were reported to have occurred, 20 records (16%) were entered on the day after the activities occurred, 6 records (5%) were entered 2 days after the activities occurred, and 2 records (2%) were entered 3 days after the activities occurred.

Handlers indicated that their dog engaged in some type of agility training or competition activity for 53 of 125 records (42%). Time spent in active agility training or competition activities for these dogs was defined as time in which the dog was actively working, excluding time that the dog may be resting between runs, while equipment is being moved, or while other dogs were working. The average time for active agility work for the 53 entries was 18.2 (SD = 10.5) minutes. An agility related RPE was provided for 52 of 53 (98%) logging entries. The median agility-related RPE for these dogs was 7 (IQR = 5–7, range = 2–10).

Of 125 logging records, 97 (77.6%) indicated that the dog had participated in one or more non-agility activities on the specified date (Table 2). An overall daily RPE was provided for 112 of 125 logging records (89.6%). The median overall RPE for all daily activities for all logging records was 4 (IQR = 3–6, range = 1–8).

All logging records included a response to the question as to whether or not the weather conditions had increased the dog's exertion level for the day. Of the 125 responses, 69 (55.2%) indicated

Questions in Revised RPE Survey

Respondent Identification

- What is your dog's name?
- For what date are you providing information?

Agility Activities

- Did you and your dog engage in any agility training or competition activities today?
- What is your estimate of the approximate time in minutes that your dog spent in active agility training or competition activities today?
- What is your rating of perceived exertion for your dog for agility training and/or competition activities that occurred on this date?

Non-agility Activities

- Did your dog participate in any of the following non-agility activities today? Check all that apply.
- Please provide a brief description of any other non-agility physical activities, not listed above, which your dog did today and any other explanatory comments related to today's activities.
- What is your rating of perceived exertion for your dog for all physical activities throughout the day?
- How much did weather conditions such as temperature, humidity, and precipitation affect your dog's physical exertion during training, conditioning, and other physical activities today?
- How much mental or emotional exertion or stress or stimulation did your dog experience today?

FIGURE 4
Revised draft daily RPE logging tool with changes implemented on the basis of comments from focus group interviews. This tool was used by handlers to provide daily RPE records for their dogs.

weather had no effect at all, 25 (20.0%) indicated it had a "little" effect, 14 (11.2%) indicated a "moderate" effect, 9 (7.2%) indicated that weather had "a lot" of effect, and 8 (6.4%) indicated that weather had a "great deal" of effect. Of the 125 logging records, 114 (91.2%) included a response to the question regarding mental exertion, stress, or stimulation on that date. The median stress rating was 4 (IQR = 3–6; range = 1–8).

Follow-up questionnaire

Responses to the follow-up questionnaire were received from 13 of 18 handlers (72.2%). Handler ratings of the ease of use of the RPE logging tool had a bimodal distribution, which clustered between 1 and 3 (very easy) and between 8 and 10 (very hard) and had no response between the two peaks. The handlers who indicated higher ease of use scores (very hard) did not make any negative comments about the daily logging experience or the logging tool. The median estimated time for completion of the daily logging was 2 min (IQR = 2–5 min; range = 2–5 min). Every respondent except 1 stated that they preferred to do their logging at the end of each day or when they believed most activity for the day was concluded. All respondents except one stated that the email logging reminders were very helpful.

Most handlers expressed some level of confidence in the accuracy of their RPE ratings; some handlers stated that the ratings became easier with time as they developed their own internal calibration for their dog's level of activities and stress. Two handlers felt that the overall daily RPE was harder to estimate than the agility related daily RPE. Only 3 handlers felt that completing the daily RPE logging record might have prompted them to modify their interactions with their dogs on that date. The question of how weather might impact exertion was raised by one handler, indicating that weather could have either a positive or negative effect and that wasn't clear in the question. All respondents indicated that they thought the RPE logging tool was ready for wider use by larger numbers of handlers. Only one handler indicated that they thought a follow-up virtual meeting would be appropriate or necessary.

Final RPE logging tool

The research team reviewed all relevant data and made minor revisions to the logging tool. Changes were intended to further clarify individual questions. No substantive changes in number of questions, data requested, or type of question asked were made. The final version of the logging RPE tool is shown in Figure 5.

TABLE 2 Frequency of indicated non-agility activities in 125 daily logging records.

Activity	Number	% (n = 125)
Running and playing alone or with other dogs	36	28.8%
Leash walk, less than 30 min	31	24.8%
No indication of other activities (no response)	28	22.4%
Leash walk, more than 30 min	26	20.8%
Core strength, balance, stretching, body awareness exercises	16	12.8%
Hiking, off leash, less than 30 min	13	10.4%
Trick training	12	9.6%
Hiking, off leash, more than 30 min	12	9.6%
Fetch activities (ball or disc)	8	6.4%
Obedience activities	6	4.8%
Nosework activities	2	1.6%
Lure coursing or Fast CAT activities	2	1.6%
Rally activities	1	0.8%
Herding or stock dog activities	1	0.8%
Swimming	0	0.0%
Flyball activities	0	0.0%
Dock jumping activities	0	0.0%
Barn hunt or earth dog activities	0	0.0%

Discussion

Monitoring athlete training load is considered critical to a science-based approach to training, fitness, and injury prevention. This report describes the development and initial evaluation of a tool that may be used by agility dog handlers to log daily activities quickly and easily and to report agility specific RPE and overall activity RPE as an aid in the measurement of training and activity load for their dog. The final RPE logging tool was developed in a six-step process that included: (1) initial drafting of an RPE logging tool by the research team; (2) review of the draft RPE logging tool with a group of US agility handlers using a semi-structured interview format and reflexive thematic analysis of their comments; (3) revision of the draft RPE logging tool by the research team; (4) seven days of activity logging by the same group of agility handlers using the revised RPE logging tool; (5) obtaining feedback from these handlers via online questionnaire; and (6) finalizing the RPE logging tool with consideration of all collected data.

The initial draft RPE logging tool was developed by the research team which included experienced researchers with deep knowledge of veterinary sports medicine and extensive personal experience in the sport of canine agility. The RPE scale as originally described by Borg ranged from 6 to 20 and was based on estimated human heart rate during exercise of 60 to 200 beats per minute (21). In the ensuing years, this scale has been adapted in a variety of ways for specific sports and user groups. For this canine RPE logging tool, a 10-point scale was used, similar to visual analog scales which are widely used for assessment of pain, and similar to modified RPE scales used for assessment of exercise intensity or training load in people and horses (15, 19). One previous description of a perceived exertion scale used for dogs on a treadmill used a 5-point scale ranging from 0, no effort noted, to 4, significant effort. For this report, the investigators chose to begin with the more common 10-point scale with the belief that agility dog handlers would be more knowledgeable of their dogs' abilities and efforts than average dog owners or observers. As a result, it was theorized that agility handlers would be able to provide a more nuanced rating of their dog's daily exertion.

The population demographics of the 18 handlers and dogs contributing to the data in this report were similar to what has been described for the overall population of agility handlers in the United States with a few notable differences. Handlers from the State of Washington were overrepresented in the group as compared to another recent study (10). This overrepresentation may have occurred because of prior acquaintance with the first author of this report. Handlers also tended to be younger than previously reported for the United States as a whole (10, 13), possibly because of greater familiarity and comfort with video-conferencing technology required for focus group interviews. Breed distributions were very similar to previous reports with border collies being most frequently included; one notable difference was the absence of mixed breed dogs in this report (32, 33). Despite these handler and dog demographic differences, the agility experiences of the dogs belonging to these handlers were very representative of the US agility population. Handlers reported competing with their dogs at all levels of competition from novice/beginner to excellent/masters and at jump heights from 8 to 24 inches. Approximately half of handlers had competed in at least one national competition in the past and their preferred venues for competition were diverse and similar to previous reports (10, 13, 32, 33).

Sample size calculation for qualitative interview or focus group studies is more nuanced than such calculations for quantitative research, but the estimates may be guided by concepts of "saturation" or "information power" (34–36). Code saturation is defined as the point at which no additional issues are identified in the data and meaning saturation is defined as the point at which no further insights or

Questions in Final RPE Survey

Respondent Identification

- What is your dog's name exactly as you provided it in the training verification survey?
- What is the unique identification number that you designated for this study?
- For what date are you providing information?

Agility Activities

- Did your dog engage in any agility training or competition activities today?
- What is your estimate of the approximate time in minutes that your dog spent in active agility training or competition activities today?
- What is your rating of perceived exertion for your dog for agility training and/or competition activities that occurred on this date?

Non-agility Activities

- Did your dog participate in any of the following non-agility activities today? Check all that apply.
- Please provide a brief description of any other non-agility physical activities, not listed above, which your dog did today and any other explanatory comments related to today's activities.
- What is your rating of perceived exertion for your dog for all physical activities throughout the day?
- How much did weather conditions such as temperature, humidity, and precipitation increase your dog's physical exertion during training, conditioning, and other physical activities today as compared to a day of ideal weather?
- How much mental or emotional exertion or stress or stimulation did your dog experience today?

FIGURE 5
Final RPE logging tool with modifications based on handler feedback in follow-up questionnaire. This RPE logging tool will be used in future studies of agility dog training loads.

nuances are found (34). It is estimated that >80% of themes are captured within two to three focus group discussions and approximately 90% of themes within three to six focus groups (37). This coincides with an estimate of reaching code saturation within four group discussions and meaning saturation within five groups (34). The concept of information power proposes that smaller samples sizes are required for studies with a narrower aim, deep knowledge of the topic by study participants, a strong theoretical background to the study, strong quality of dialogue (often related to the research experience and skills of the interviewer), and an analytic strategy using in-depth analysis of narratives. All of these criteria were considered applicable to this project. As a result, considering the concepts of saturation and information power, it is concluded that the participant sample size and the number of focus groups were sufficient to collect the desired information for this project.

Analysis of data from focus group meetings was performed using the detailed contemporaneous notes of the first author. The lack of availability of video recordings or verbatim transcripts of the discussions may have decreased the richness of the qualitative analysis of the content of these meetings. Given the sample size (number of individuals and number of group sessions), however, it is likely that the most important codes and themes were identified. Reflexive thematic analysis is a common tool for analysis of qualitative psychological and sociological research data (31) but is rarely used in veterinary research. This analytical approach highlights the researcher's active role in knowledge production through their engagement with the data and thematic conclusions (38). For the data analyzed in this report, it was a useful strategy to achieve the very narrow goal of optimizing the daily RPE logging tool for agility dogs. Through an iterative process of coding data and identifying themes, important insights into the clarity and ease of use of the RPE logging tool were identified and used to produce a revised draft tool. More importantly, this approach clearly identifies the need to develop online, accessible training options prior to wider implementation of the RPE logging tool and provides explicit suggestions and ideas for training content. These training materials should include both written and video options to maximize accessibility and ensure inclusive access to the information for diverse populations.

Revisions to the RPE logging tool included the addition of questions related to the effects of weather on agility related exertion and the effects of mental or emotional factors on overall exertion for the day. The addition of these questions was supported by results of reflexive thematic analysis and by evidence from human literature. Mental fatigue is well-documented to cause lowered performance in human athletes, with negative effects on technical and decision-making skills (39) and an association with greater perceived exertion (40). The overall level of life stress of the handler may also impact the dog's performance in that long-term stress levels may be synchronized between dogs and handlers (41). Adverse weather conditions can greatly affect the amount of perceived exertion of athletes (42).

The observations that the average time for daily logging entry was <2 min and that nearly 95% of entries occurred within 1 calendar day of the events being logged support the general conclusion that the revised RPE logging tool was quick and easy to use by handlers in this study. The actual data logged provided interesting insights into agility training load. Fewer than half of the logging records indicated that the dog engaged in any specific agility-related activities during that logging day and more than 75% of records indicated that dogs engaged in a broad range of other types of athletic activities. Collectively, this strongly suggests that agility dogs promote and maintain athletic readiness through cross-training in other disciplines that can improve both physical and mental fitness. This is a hypothesis that should be further explored in more robust prospective studies.

In the final follow-up questionnaire, handlers expressed an overall high level of satisfaction with the RPE logging tool and its ease of use. Handlers expressed some confusion regarding the wording of the question related to weather effects on athletes. Comments in the follow-up questionnaire indicated that this could be interpreted as either a positive or a negative effect. The wording for this sentence was clarified in the final RPE logging tool. Other suggestions included in the responses to this final questionnaire largely related to requests for more sophisticated functionality including optimization of reminders, ability to review previous logging entries, and ability to produce summary reports. This functionality could easily be provided in a smartphone application with more flexible programming options than are available in the web-based software used for this project.

Overall, this work describes the process of development and initial testing of a daily RPE logging tool that may be used as an aid in the assessment of activity load in agility dogs. This approach and the resultant RPE logging tool could easily be adapted to monitor exertion levels in other types of canine athletes. Prior to widespread use, however, the daily RPE logging tool should be tested with a larger group of handlers and dogs over a longer period of time, work that is already in progress. In addition, validation of handler ratings should occur by comparison of RPE ratings with physiologic parameters such as heart rate or inertial measurement units (43, 44). Development of an application for use on mobile devices would allow for customization of preferences and utilization for a variety of canine athletes. Such customization should include direct access links to specific training videos and examples, automated integration with weather information, automated integration with heart rate or activity monitors, and customizable reminder and reward systems to improve consistency of daily logging. When fully validated and programmed as a smart-phone application, the agility RPE logging tool could be extremely valuable as a research tool for prospective studies of the effects of training load on performance and injury. Because of its ease of use and low cost, this tool will likely prove useful to individual handlers as an aid in planning, implementation, and monitoring of specific training and conditioning strategies.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Institutional Review Board of Washington State University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

DS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AS: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – review & editing. AP: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – review & editing. DM: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – review & editing. DM-L: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This project was funded by the American Kennel Club's Canine Health Foundation Grant #03180-A.

Acknowledgments

The authors gratefully acknowledge the assistance and support of Dr. Molly McCue in the design and implementation of this project.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer MB declared a past co-authorship with the authors DM-L and AS to the handling editor.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2024.1473977/full#supplementary-material

References

1. Cullen KL, Dickey JP, Bent LR, Thomason JJ, Moens NM. Survey-based analysis of risk factors for injury among dogs participating in agility training and competition events. *J Am Vet Med Assoc*. (2013) 243:1019–24. doi: 10.2460/javma.243.7.1019

2. Cullen KL, Dickey JP, Bent LR, Thomason JJ, Moens NM. Internet-based survey of the nature and perceived causes of injury to dogs participating in agility training and competition events. *J Am Vet Med Assoc*. (2013) 243:1010–8. doi: 10.2460/javma.243.7.1010

3. Inkilä L, Hyytiänen HK, Hielm-Björkman A, Junnila J, Bergh A, Boström A. Part II of Finnish agility dog survey: agility-related injuries and risk factors for injury in competition-level agility dogs. *Animals*. (2022) 12:227. doi: 10.3390/ani12030227

4. Kerr ZY, Fields S, Comstock RD. Epidemiology of injury among handlers and dogs competing in the sport of agility. *J Phys Act Health*. (2014) 11:1032–40. doi: 10.1123/jpah.2012-0236

5. Levy M, Hall C, Trentacosta N, Percival M. A preliminary retrospective survey of injuries occurring in dogs participating in canine agility. *Vet Comp Orthop Traumatol*. (2009) 22:321–4. doi: 10.3415/VCOT-08-09-0089

6. Pechette Markley A, Shoben AB, Kieves NR. Internet-based survey of the frequency and types of orthopedic conditions and injuries experienced by dogs competing in agility. *J Am Vet Med Assoc*. (2021) 259:1001–8. doi: 10.2460/javma.259.9.1001

7. Tomlinson JE, Manfredi JM. Return to sport after injury: a web-based survey of owners and handlers of agility dogs. *Vet Comp Orthop Traumatol*. (2018) 31:473–8. doi: 10.1055/s-0038-1670676

8. Evanow JA, VanDeventer G, Dinallo G, Mann S, Frye CW, Wakshlag JJ. Internet survey of participant demographics and risk factors for injury in competitive agility dogs. *Vet Comp Orthop Traumat Open*. (2021) 4:e92–8. doi: 10.1055/s-0041-1735843

9. Essner A, Kjellerstedt C, Hesbach AL, Igelström H. Injuries and associated factors in Swedish sporting and utility trial dogs-a cross-sectional study. *Animals (Basel)*. (2024) 14:398. doi: 10.3390/ani14030398

10. Sellon DC, Marcellin-Little DJ, McFarlane D, McCue M, Pechette Markley A, Shoben A. Adverse health events and recommended health research priorities in agility dogs as reported by dog owners. *Front Vet Sci*. (2023) 10:1127632. doi: 10.3389/fvets.2023.1127632

11. Impellizzeri FM, Shrier I, McLaren SJ, Coutts AJ, McCall A, Slattery K, et al. Understanding training load as exposure and dose. *Sports Med*. (2023) 53:1667–79. doi: 10.1007/s40279-023-01833-0

12. Lima-Alves A, Claudino JG, Boullosa D, Couto CR, Teixeira-Coelho F, Pimenta EM. The relationship between internal and external loads as a tool to monitor physical fitness status of team sport athletes: a systematic review. *Biol Sport*. (2022) 39:629–38. doi: 10.5114/biolsport.2022.107021

13. Sellon DC, Marcellin-Little DJ. Risk factors for cranial cruciate ligament rupture in dogs participating in canine agility. *BMC Vet Res*. (2022) 18:39. doi: 10.1186/s12917-022-03146-2

14. Eckard TG, Padua DA, Hearn DW, Pexa BS, Frank BS. The relationship between training load and injury in athletes: a systematic review. *Sports Med*. (2018) 48:1929–61. doi: 10.1007/s40279-018-0951-z

15. Foster C, Boullosa D, McGuigan M, Fusco A, Cortis C, Arney BE, et al. 25 years of session rating of perceived exertion: historical perspective and development. *Int J Sports Physiol Perform*. (2021) 16:612–21. doi: 10.1123/ijspp.2020-0599

16. Foster C, Rodriguez-Marroyo JA, de Koning JJ. Monitoring training loads: the past, the present, and the future. *Int J Sports Physiol Perform*. (2017) 12:S2-2–8. doi: 10.1123/ijspp.2016-0388

17. Soligard T, Schwellnus M, Alonso JM, Bahr R, Clarsen B, Dijkstra HP, et al. How much is too much? (part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med*. (2016) 50:1030–41. doi: 10.1136/bjsports-2016-096581

18. Cogger N, Perkins N, Hodgson DR, Reid SW, Evans DL. Risk factors for musculoskeletal injuries in 2-year-old thoroughbred racehorses. *Prev Vet Med*. (2006) 74:36–43. doi: 10.1016/j.prevetmed.2006.01.005

19. Crawford KL, Finnane A, Greer RM, Barnes TS, Phillips CJC, Woldeyohannes SM, et al. Survival analysis of training methodologies and other risk factors for musculoskeletal injury in 2-year-old thoroughbred racehorses in Queensland, Australia. *Front Vet Sci*. (2021) 8:698298. doi: 10.3389/fvets.2021.698298

20. Sylvia LG, Bernstein EE, Hubbard JL, Keating L, Anderson EJ. Practical guide to measuring physical activity. *J Acad Nutr Diet*. (2014) 114:199–208. doi: 10.1016/j.jand.2013.09.018

21. Borg G. Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med*. (1970) 2:92–8. doi: 10.2340/1650197719702239298

22. Drew MK, Finch CF. The relationship between training load and injury, illness and soreness: a systematic and literature review. *Sports Med*. (2016) 46:861–83. doi: 10.1007/s40279-015-0459-8

23. Haddad M, Stylianides G, Djaoui L, Dellal A, Chamari K. Session-RPE method for training load monitoring: validity, ecological usefulness, and influencing factors. *Front Neurosci*. (2017) 11:612. doi: 10.3389/fnins.2017.00612

24. Scherr J, Wolfarth B, Christle JW, Pressler A, Wagenpfeil S, Halle M. Associations between Borg's rating of perceived exertion and physiological measures of exercise intensity. *Eur J Appl Physiol*. (2013) 113:147–55. doi: 10.1007/s00421-012-2421-x

25. Robertson RJ, Goss FL, Aaron DJ, Tessmer KA, Gairola A, Ghigiarelli JJ, et al. Observation of perceived exertion in children using the OMNI pictorial scale. *Med Sci Sports Exerc*. (2006) 38:158–66. doi: 10.1249/01.mss.0000190595.03402.66

26. Robertson RJ, Goss FL, Aaron DJ, Utter AC, Nagle E. OMNI scale rating of perceived exertion at ventilatory breakpoint by direct observation of children's kinematics. *Percept Mot Skills*. (2007) 104:975–84. doi: 10.2466/pms.104.3.975-984

27. Swanson KDJ, Harper TAM, McMichael M, Fries RC, Lascola KM, Chandler C, et al. Development of a perceived exertion scale for dogs using selected physiologic parameters. *J Small Anim Pract*. (2019) 60:247–53. doi: 10.1111/jsap.12978

28. Tabor G, Marlin D, Williams J. eds. Can human training load quantification be applied to equine training? Poster session presented at 10th international conference on equine exercise physiology, Lorne, Australia. (2018).

29. Murphy MC, Glasgow P, Mosler AB. Self-reported measures of training exposure: can we trust them, and how do we select them? *Br J Sports Med*. (2021) 55:891–2. doi: 10.1136/bjsports-2021-104498

30. Sylta O, Tonnessen E, Seiler S. Do elite endurance athletes report their training accurately? *Int J Sports Physiol Perform*. (2014) 9:85–92. doi: 10.1123/ijspp.2013-0203

31. Braun V, Clarke V. Using thematic analysis in psychology. *Qual Res Psych*. (2006) 3:77–101. doi: 10.1191/1478088706qp063oa

32. Sellon DC, Martucci K, Wenz JR, Marcellin-Little DJ, Powers M, Cullen KL. A survey of risk factors for digit injuries among dogs training and competing in agility events. *J Am Vet Med Assoc*. (2018) 252:75–83. doi: 10.2460/javma.252.1.75

33. Sundby AE, Pechette Markley A, Shoben AB, Kieves NR. Internet survey evaluation of demographic risk factors for injury in canine agility athletes. *Front Vet Sci*. (2022) 9:869702. doi: 10.3389/fvets.2022.869702

34. Hennink MM, Kaiser BN, Weber MB. What influences saturation? Estimating sample sizes in focus group research. *Qual Health Res*. (2019) 29:1483–96. doi: 10.1177/1049732318821692

35. Malterud K, Siersma VD, Guassora AD. Sample size in qualitative interview studies: guided by information power. *Qual Health Res*. (2016) 26:1753–60. doi: 10.1177/1049732315617444

36. Sebele-Mpofu FY. Saturation controversy in qualitative research: complexities and underlying assumptions. A literature review. *Cogent Soc Sci*. (2020) 6:1838706. doi: 10.1080/23311886.2020.1838706

37. Guest G, Namey E, McKenna K. How many focus groups are enough? Building an evidence base for nonprobability sample sizes. *Field Method*. (2017) 29:3–22. doi: 10.1177/1525822x16639015

38. Byrne D. A worked example of Braun and Clarke's approach to reflexive thematic analysis. *Qual Quant*. (2021) 56:1391–412. doi: 10.1007/s11135-021-01182-y

39. Sun H, Soh KG, Roslan S, Wazir M, Soh KL. Does mental fatigue affect skilled performance in athletes? A systematic review. *PLoS One*. (2021) 16:e0258307. doi: 10.1371/journal.pone.0258307

40. Van Cutsem J, Marcora S, De Pauw K, Bailey S, Meeusen R, Roelands B. The effects of mental fatigue on physical performance: a systematic review. *Sports Med*. (2017) 47:1569–88. doi: 10.1007/s40279-016-0672-0

41. Sundman AS, Van Poucke E, Holm ACS, Faresjo A, Theodorsson E, Jensen P, et al. Long-term stress levels are synchronized in dogs and their owners. *Sci Rep*. (2019) 9:7391. doi: 10.1038/s41598-019-43851-x

42. Maw GJ, Boutcher SH, Taylor NA. Ratings of perceived exertion and affect in hot and cool environments. *Eur J Appl Physiol Occup Physiol*. (1993) 67:174–9. doi: 10.1007/BF00376663

43. Albert JA, Herdick A, Brahms CM, Granacher U, Arnrich B. Using machine learning to predict perceived exertion during resistance training with wearable heart rate and movement sensors. IEEE international conference on bioinformatics and biomedicine (BIBM), Houston, TX, USA. (2021).

44. Papi E, Osei-Kuffour D, Chen YM, McGregor AH. Use of wearable technology for performance assessment: a validation study. *Med Eng Phys*. (2015) 37:698–704. doi: 10.1016/j.medengphy.2015.03.017

Frontiers in
Veterinary Science

Transforms how we investigate and improve animal health

The third most-cited veterinary science journal, bridging animal and human health with a comparative approach to medical challenges. It explores innovative biotechnology and therapy for improved health outcomes.

Discover the latest Research Topics

See more →