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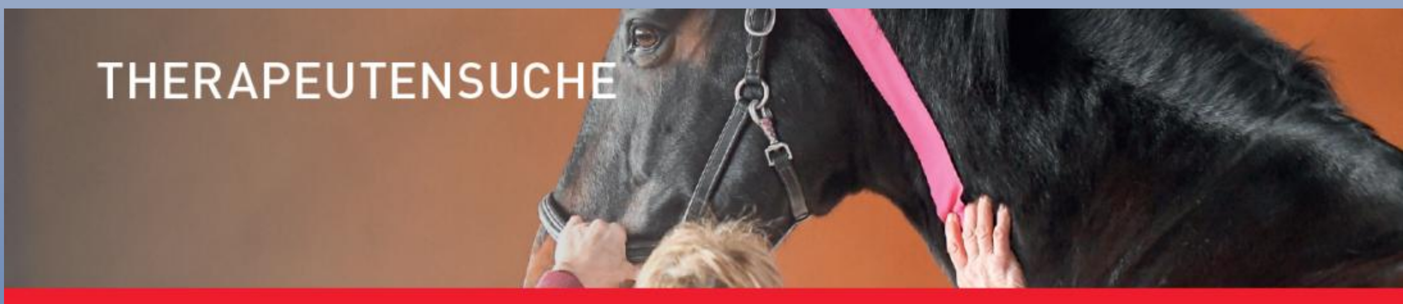
SCHWEIZERISCHER VERBAND FÜR TIERPHYSIOTHERAPIE ®
FEDERATION SUISSE DE PHYSIOTHERAPIE POUR ANIMAUX
FEDERAZIONE SVIZZERA DELLA FISIOTERAPIA PER ANIMALI
FEDERAZIUN SVIZRA DE LA FISIOTERAPIA PER BES-CHAS

Infojournal 2025



Inhaltsverzeichnis 2025

Weiterbildung

Fallbeispiel

Verband

Wissen

Pferde

Wissen

Hunde

Shop

Liebe Mitglieder

Es freut mich euch zur 27. Ausgabe unseres jährlichen Infojournals zu begrüßen.

Ein Prüfungs- und Kongressfreies Jahr ist im Gange. Das heisst nur die Abwicklung dieser 2 grossen Projekte findet dieses Jahr turnusgemäss nicht statt. Trotzdem laufen die Vorbereitungen auf Hochtouren. Vor allem die Vorbereitungen für den 3. Internationalen hybriden Kongress im Horse Park Zürich- Dielsdorf nehmen viel Zeit in Anspruch. Namhafte Referenten sind bereits verpflichtet. Lest dazu den detaillierten Artikel im Journal.

Unsere etablierten Projekte wie Zusatzausbildung, Weiterbildung für unsere Mitglieder, Newsletter, Berufsanerkennung und kantonale Berufsbewilligung laufen konstant weiter. Wie immer sind wir stets bemüht in der Sicherung der Qualität unserer Arbeit.

Dies alles hat seinen Preis. Unsere Einnahmequellen sind limitiert: Mitgliederbeiträge, und ein kleiner Gewinn aus den organisierten Weiterbildungen. Dem gegenüber stehen ordentliche Ausgaben. Die Mitglieder sollen nicht mit hohen Beiträgen vergrault werden, die Teilnehmer der Weiterbildungen sollen so viel bezahlen, dass alle Unkosten und Honorare gedeckt sind, die Organisation und Durchführung der HFP wird vom Bund unterstützt, aber der Verband als Trägerschaft bezahlt abzüglich der Prüfungsgebühren noch bis ca. 30% der Kosten. Die Teilnehmergebühren der ZA sind für diese gebunden und die Abrechnung der Ausbildung läuft getrennt vom Verband.

Wir suchen nach zusätzlichen Ressourcen. Kurzfristig um die Kasse zu entlasten, hat der Vorstand sich entschieden die restlichen Sitzungen in diesem Jahr ohne Entschädigung zu tätigen, das Kongress – OK arbeitet vollumfänglich ehrenamtlich, die Präsidentin arbeitet fast nur ehrenamtlich und doch brauchen wir Geld. Wir brauchen Gönnermitglieder, die uns und unseren wichtigen Beruf und dessen Stellungswert in der Tiergesundheit unterstützen und einen oder lieber mehrere Sponsoren, denen unsere Arbeit am Herzen liegt. Kein Berufsverband kann ohne solche externen Geldquellen existieren. Liebe Mitglieder: werbt unter euren Kunden und Zuweisern Gönnermitglieder (mit CHF 50.- ist man bereits dabei!) Wer kennt potentielle Sponsoren? Meldet euch bei der Geschäftsführung Isabelle Gysi. Wir zählen auf euch!

Die PR für unseren wunderbaren Beruf läuft in den Printmedien wie Kavallo, Passion und Hundemagazin der SKG. Andererseits durch Präsenz in den Sozialen Netzwerken wie Facebook, Instagramm und Linkedin. Dieses Jahr waren wir auch wieder an der OFFA mit einem Stand vertreten. Zusätzlich werden wir im August an der OBA (Ostschweizer Berufsausstellung) vertreten sein. Es ist wichtig an solchen Veranstaltungen Präsenz zu markieren. Leider ist auch das mit anständigen Kosten verbunden, obwohl alle Standbetreuenden Mitglieder das ehrenamtlich machen.Kosten hin oder her, wir dürfen uns nicht verstecken, wir brauchen die Präsenz.

Wir sind sehr dankbar um Mithilfe unserer Mitglieder und freuen uns, dass einige junge und enthusiastische Leute unter uns sind und uns unterstützen, und immer gute Ideen mitbringen.

Viel Spass beim Studium des diesjährigen Info – Journals und herzlichen Dank für jegliche Unterstützung.

Bachs, im Juli 2025 Brigitte Stebler

Um den Titel „Tierphysiotherapeut/in mit eidgenössischem Diplom“ zu erhalten, ist neben der bestandenen theoretischen und praktischen Prüfung auch die Abgabe einer Diplomarbeit erforderlich. In diesem Jahrgang wurden 16 genügende Diplomarbeiten eingereicht. Die Zusammenfassungen dieser Arbeiten befinden sich auf den folgenden Seiten.

Bächi Lea

Das Sidewinder Syndrom des Pferdes

Ist die physiotherapeutische Behandlung eine geeignete Therapie bei Pferden mit Sidewinder Syndrom?

Der Begriff des Sidewinder Syndroms ist noch vielen unbekannt und es existiert wenig Literatur dazu. Diese wird dargelegt. Zudem werden mit einer kleinen, fünf Pferde umfassenden Fallstudie physiotherapeutisch relevante Aspekte des Sidewinder Syndroms analysiert.

Vom Sidewinder Syndrom betroffen sind in der Regel ältere Pferde. Ohne dass ein Zwischenfall beobachtet worden wäre, stehen sie akut mit komplett schiefem Rumpf und schiefer Hinterhand da. Die Vorhand ist zumeist eher unauffällig. Im Schritt gehen sie auf drei Hufschlägen. Schlimmer betroffene Patienten können kaum ruhig stehen; sie korrigieren ständig in die gleiche Richtung, um das Gleichgewicht halten zu können, was dazu führen kann, dass sie sich im Kreis drehen.

Den Studienpferden ist gemeinsam, dass sie in ihrer Schiefe im Stand und im Schritt in der gleichen Diagonalen sind, diese aber im Verlauf der Erkrankung mehrfach wechseln können. Die im Stand häufig auffällig abduzierte Hintergliedmasse, die zudem einen deutlich erhöhten Tonus der Adduktoren aufweist, übernimmt die Funktion des Standbeins.

Die Ätiologie respektive Pathogenese der Erkrankung sind noch unbekannt, weshalb noch nicht gezielt behandelt werden kann. Eingesetzt werden sowohl Medikamente, insbesondere nichtsteroidale und steroidale Entzündungshemmer, sowie ein breites Spektrum der Komplementärmedizin. Die Physiotherapie scheint zumindest bei einigen Sidewinder Patienten massgeblich zur Besserung der Symptomatik beizutragen.

Bezüglich Prognose liegen noch keine genauen Zahlen vor. Es hat sich aber gezeigt, dass der Zeitfaktor entscheidend ist, weil sich viele Patienten im Verlauf der Zeit verbessern. Sie können zwischendurch auch kleinere Rückschläge erleiden. Eine vollständige Genesung tritt wohl eher nicht ein, die Patienten scheinen aber durchaus Lebensqualität zu haben, geniessen ihr Leben auf der Weide, werden spaziert und in seltenen Fällen auch noch geritten. Die meisten haben schon das Seniorenalter erreicht und sind teilweise bereits vor Ausbruch des Syndroms pensioniert worden.

Binz Angela Cristina

Coxarthrose bei der Katze

Aufarbeitung der funktionellen Einschränkungen bei Katzen mit Coxarthrose, Erstellen eines Heimübungsprogramms sowie Aufzeigen weiterer unterstützender Massnahmen

Die Coxarthrose wird bei der Katze in der tierärztlichen Praxis oft unterdiagnostiziert, obwohl sie weit verbreitet ist. Die betroffenen Katzen leiden meist unter chronischen Schmerzen und zeigen Verhaltensveränderungen. Als Folge der Minder- und Fehlbelastungen kann sich die Coxarthrose auf den ganzen Körper auswirken und zu artikulären, muskulären faszialen und neuralen funktionellen Einschränkungen führen.

Diese Diplomarbeit beleuchtet die verschiedenen Aspekte und Auswirkungen der Coxarthrose bei Katzen. Zudem werden ein einfaches Heimübungsprogramm sowie unterstützende Massnahmen vorgestellt, welche dazu beitragen können, die Lebensqualität der Katze zu verbessern.

Fahr Emilien

Die Übertragung der FDM-Therapie (Fasziendistortionsmodell nach Typaldos) von der Humanmedizin zur Tiermedizin, insbesondere bei Pferden

Was genau ist das Fasziendistortionsmodell (FDM) und inwiefern lässt sich die FDM-Therapie auf Tiere übertragen? Sind die Anatomie und die physiologischen Systeme ausreichend ähnlich, um die Methode wirksam anzuwenden?

Faszien stehen zunehmend im Mittelpunkt wissenschaftlicher Forschung und werden immer intensiver untersucht. Ihr Einfluss auf muskuloskelettale Schmerzen wird zunehmend anerkannt, und sie werden als wichtiger Faktor in der Entstehung und Behandlung solcher Beschwerden betrachtet. Das Faszien-Distorsions-Modell (FDM), entwickelt von Dr. Stephen Typaldos, bietet eine Methode zur Behandlung von Funktionsstörungen, bei der der Fokus auf die Faszien und deren Distorsionen gelegt wird. In der Humanphysiotherapie hat sich das FDM als wirksam erwiesen, um verschiedene Beschwerden und Schmerzen zu erkennen und zu lindern. Ziel dieser Arbeit ist es, die Möglichkeit zu untersuchen, diese Methode auf Pferde zu übertragen, unter Berücksichtigung ihrer spezifischen Anatomie und Physiologie. Die Anpassungsfähigkeit des FDM bei Pferden, sein therapeutisches Potenzial und die Vorteile, die es im Rahmen der Rehabilitation von Pferden bieten könnte, sind Themen, die in dieser Arbeit analysiert werden.

Frei Elio

Dry Needling am Hund

Eine Anleitung zur sicheren Anwendung von Dry Needling am Beispiel ausgewählter Muskeln

Diese Arbeit untersucht die sichere Anwendung von Dry Needling (DN) zur Behandlung myofaszialer Triggerpunkte (mTrP) bei Hunden. Ziel ist es, eine praxisnahe Anleitung für Tierphysiotherapeuten zu entwickeln, die DN-Therapie bei Hunden einsetzen möchten. Um eine mögliche Herangehensweise zu erstellen, werden in dieser Arbeit zuerst die physiologischen Wirkungen von DN, allgemeine Indikationen beziehungsweise Kontraindikationen, sowie mögliche Gefahrenzonen thematisiert. Hauptbestandteil der Arbeit ist die Erstellung einer Anleitung, um einen Muskel sicher mit DN behandeln zu können und unnötige Risiken zu vermeiden. Als Vorlage dieser Anleitung dient die Ausbildung zum DN-Therapeuten in der Humanphysiotherapie durch die DGSA (David G. Simons Academy). Als konkrete Beispiele werden die Muskeln Musculus (M.) biceps brachii und M. gastrocnemius medialis verwendet. Anhand diverser Anatomieunterlagen, durch Abbildungen von Muskelquerschnitten sowie je einem Fallbeispiel, wird eine Möglichkeit aufgezeigt, um diese beiden Muskeln sicher zu stechen.

Die beiden Fallbeispiele können als Erfolg gewertet werden, da bei beiden Muskeln eine klare Local Twitch Response (LTR) ausgelöst werden konnte. Nach dem DN wurden ebenfalls keine Beschwerden oder Komplikationen von den Besitzern gemeldet. Demnach kann davon ausgegangen werden, dass die erarbeitete Vorgehensweise funktioniert und angewendet werden kann. Diese Herangehensweise kann demnach als eine mögliche Vorlage für Tierphysiotherapeuten/-innen dienen, um andere Muskeln nach dem gleichen Prinzip sicher mit DN zu behandeln. Um fundierte Aussagen über die Effizienz von DN treffen zu können, sind weitere Studien erforderlich. Wichtiger Bestandteil dieser Arbeit ist auch aufzuzeigen, wie wichtig es ist, dass jede Tierphysiotherapeutin und jeder Tierphysiotherapeut potenzielle Gefahrenzonen erkennen, bevor ein Muskel genadelt wird. Es wird dringend davon abgeraten, ohne jegliche Erfahrung DN anzuwenden.

Galli Jasmin

Steigerung der Lebensqualität durch Physiotherapie bei asthmatischen Patienten

Eine theoretische Analyse, wie Behandlungstechniken aus der humanen Physiotherapie bei Katzen mit Asthma angewendet werden könnten.

Die Physiotherapie wird in der Humanmedizin ergänzend zu der medikamentösen Therapie in der Behandlung von Asthma benutzt, um eine bessere Lebensqualität der Patienten zu erreichen. In dieser Arbeit soll theoretisch analysiert werden, ob die Physiotherapie auch bei felinen Patienten mit Asthma eine mögliche Behandlungsform sein kann, um die Lebensqualität der Patienten zu verbessern. Mittels Vergleichen der respiratorischen Anatomie, Physiologie und der Krankheitsbilder beider Spezies, können Parallelen und Unterschiede eruiert werden, um humanphysiotherapeutische Methoden für feline Patienten theoretisch zu evaluieren. Diese Methoden umfassen Atemübungen, das Training der inspiratorischen Atemmuskulatur, sportliche Aktivität, Atemwegs Clearance und manuelle Therapien.

Die theoretische Analyse zeigt, dass viele Methoden aus der Humanphysiotherapie übernommen werden könnten, wobei die meisten davon auf den felinen Patienten angepasst werden müssen. Andere Methoden, mitunter die Atemübungen, sind sehr schwierig bei felinen Patienten umzusetzen und andere Lösungen müssen gesucht werden, um bei der Katze ähnliche Ziele wie eine tiefe und relaxierte Atmung zu erreichen. Die Arbeit kann so als Anregung für praktizierende Tierphysiotherapeuten dienen, ihre Fähigkeiten bei asthmatischen Katzen zu nutzen. Ebenso kann sie eine Hilfestellung sein, den Besitzern Empfehlungen abzugeben für ein besseres Management der Katze in ihrem Zuhause. Die Analyse kann auch ein Anreiz sein, diese Methoden klinisch zu evaluieren und zukünftig wissenschaftlich geprüfte Methoden empfehlen zu können.

Gass Nadine

Optimales Warm-up und Cool-down für Agility-Hunde zur Prävention von Sportverletzungen

Wie gestaltet sich das optimale Warm-up und Cool-down für einen Agility-Hund unter Berücksichtigung der biomechanischen Abläufe?

Agility ist eine anspruchsvolle Sportart, bei der Hunde im Parcours Sprintschnelligkeit, Sprungkraft, Beweglichkeit und koordinative Fähigkeiten unter Beweis stellen müssen. In den letzten Jahren hat sich der Fokus im Agility besonders auf Geschwindigkeit gelegt, was die Anforderungen an die Hunde erheblich erhöht. Die gesteigerte Belastung kann zu erhöhtem Verletzungsrisiko führen. Neben akuten Traumata können insbesondere chronisch-repetitive Verletzungen des Muskel-Sehnen-Apparats auftreten, die zu Lahmheiten und funktionellen Bewegungseinschränkungen führen können. Besonders betroffen hiervon sind die Schulter- und Rückenregion.

Vor diesem Hintergrund ist eine sorgfältige Vorbereitung vor dem Training oder Wettkampf für die Gesundheit und Leistungsfähigkeit der Agility-Hunde entscheidend. Ein gezieltes Warm-up bereitet den Bewegungsapparat, das Herz-Kreislauf-System und das Nervensystem des Hundes optimal auf die bevorstehende Belastung vor. Nach der sportlichen Tätigkeit ist ein richtiges Cool-down wichtig, um die regenerativen Prozesse zu fördern, Stoffwechselendprodukte schneller abzutransportieren und Muskelverspannungen vorzubeugen.

Für Tierphysiotherapeutinnen ist es daher von grosser Bedeutung, Hundehalterinnen umfassend über das Warm-up und Cool-down zu instruieren und dessen Wichtigkeit angesichts der enormen Belastungen auf den Bewegungsapparat der Hunde hervorzuheben. Die vorliegende Diplomarbeit beschäftigt sich eingehend mit diesen Themen und beschreibt ein eigens aufgestelltes Warm-up und Cool-down Programm, das auf die besonderen Anforderungen des Agility abgestimmt ist. Das Programm ist in Form eines Leitfadens mit anschaulichen Bildern und Instruktionen für Hundehalterinnen ausgestaltet, um eine einfache und praktische Umsetzung zu ermöglichen.

Gysin Tina

Intensivkurs „Fit im Alter“ für Hunde

Planung und Durchführung eines fünfwöchigen Intensivkurses
für Besitzer von frühalten Hunden

Im Rahmen der vorliegenden Arbeit wurde ein fünfwöchiger Intensivkurs zum Thema «Fit im Alter» für Hundebesitzer von Hunden im Alter von 6-11 Jahren geplant und durchgeführt. Der Kurs umfasste ein Einführungsvideo, vier Trainingseinheiten mit Übungen aus der aktiven Hundephysiotherapie sowie einen Theorieabend zur Aufklärung der Besitzer über altersbedingte Beschwerden von Hunden. Zudem wurde untersucht, ob durch den Kurs messbare Veränderungen von Kraft, Beweglichkeit und Koordination bei zwei Hunden erzielt werden konnten. Dafür wurden die Hunde vor und nach dem Kurs unter tierphysiotherapeutischen Aspekten untersucht, Bewegungsabläufe auf Video aufgezeichnet und die Befunde verglichen. Bei beiden Hunden konnten nach Beendigung des Kurses Verbesserungen festgestellt werden. Die Körperhaltung, die Rumpfstabilität, die Beweglichkeit, die Koordination auf dem Balancepad und der Muskelumfang der schwächeren Gliedmaßen haben sich nach dem Kurs bei beiden verbessert. Auch das Feedback der teilnehmenden Hundebesitzer war nach dem Kurs äußerst positiv.

Der Intensivkurs fördert durch das präventive kontrollierte Training die Gesunderhaltung der Hunde im Alter und bietet Hundebesitzern eine hervorragende Möglichkeit, Sicherheit im Umgang mit ihren älter werdenden Vierbeinern zu erlangen. Gleichzeitig ist der Kurs für den/die Hundephysiotherapeuten/in eine sehr gute Lösung, um in einer Gruppenstunde mehrere Patienten beim aktiven Training individuell zu begleiten und Fehler direkt zu korrigieren. Auf diese Weise können angeordnete Aufgaben in Kombination mit der Physiotherapie in der Praxis dazu beitragen, das angestrebte Behandlungsziel zu erreichen und den Bewegungsapparat der Hunde beim Altern bestmöglich zu unterstützen und so das Wohlbefinden der Senioren zu steigern.

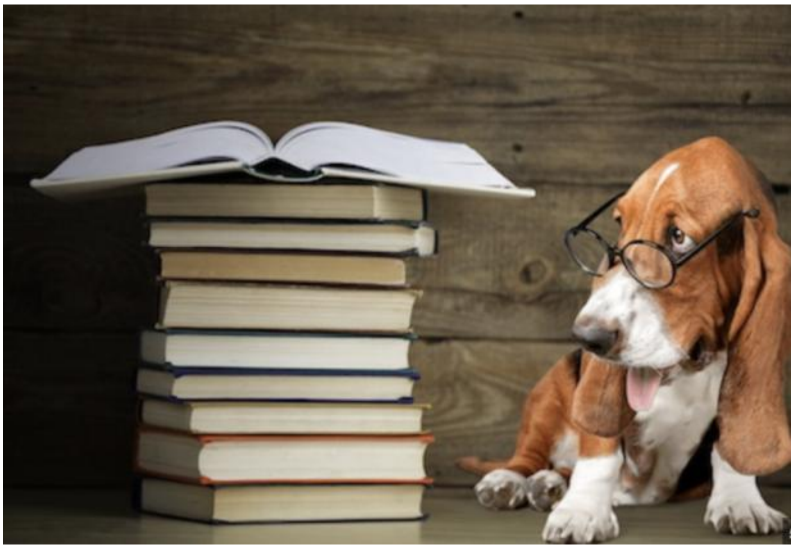
Haller Manuela

Analyse der Evidenzlage in der Tierphysiotherapie

Eine Literaturrecherche

Tierphysiotherapie ist eine immer häufiger angewendete Behandlungsmethode. Unter dem Begriff Tierphysiotherapie werden unterschiedliche Behandlungstechniken verstanden, welche präventiv zur Gesunderhaltung oder nach einem Trauma oder einer Krankheit eingesetzt werden können. Auch heute ist es noch so, dass viele Tierärzte kritisch gegenüber der Tierphysiotherapie stehen.

Das Ziel dieser Arbeit ist es, einen Überblick über die Evidenzlage verschiedener tierphysiotherapeutischer Behandlungstechniken zu verschaffen und die Qualität dieser eventuell gefundenen Evidenz kritisch zu hinterfragen. Nebenbei soll auch aufgezeigt werden welche, der im Rahmen des Lehrgangs zur höheren Fachprüfung unterrichteten Behandlungstechniken, evidenz-basiert sind oder wie gegebenenfalls die Evidenz verbessert werden könnte.



Mittels einer systematischen Literaturrecherche ergänzt mit einer Literaturrecherche mittels Schneeballsystem, wird ein Überblick der verfügbaren Publikationen über folgende Behandlungstechniken erarbeitet: manuelle Techniken, manuelle Lymphdrainage, Massage, apparative Techniken und aktive Therapie.

Es kann gezeigt werden, dass die Evidenz in der Tierphysiotherapie für einige Behandlungstechniken, wie beispielsweise aktive Therapie und Massage durchaus gut ist. Zu Behandlungstechniken wie Faszientechniken oder auch gewisse apparative Behandlungstechniken gibt es aber kaum bis gar keine Evidenz. In Fällen mit vorhandener Evidenz, muss diese grundsätzlich sehr kritisch hinterfragt werden. So fällt auf, dass viele Publikationen nur Beobachtungsstudien ohne Kontrollgruppen sind oder klinische Fallpräsentationen einzelner Tiere oder sehr kleiner, teils nicht repräsentativer Stichprobengruppen sind.

Klar ist, dass die Evidenzlage in der Tierphysiotherapie weiter verbessert werden muss, da nicht alle Ergebnisse aus der humanmedizinischen Forschung direkt auf das Tier zu übertragen sind. Eine mögliche Verbesserungsmöglichkeit wäre, dass der Schweizerische Verband für Tierphysiotherapie Forschungsbeziehungen beispielsweise mit den Universitäten oder grösseren Tierkliniken eingeht, um gute Forschung mit genügend Praxisfällen vorantrieben zu können, dies eventuell auch im Rahmen von zukünftigen Diplomarbeiten oder Dissertationen.

Imboden – de Bont Margaretha

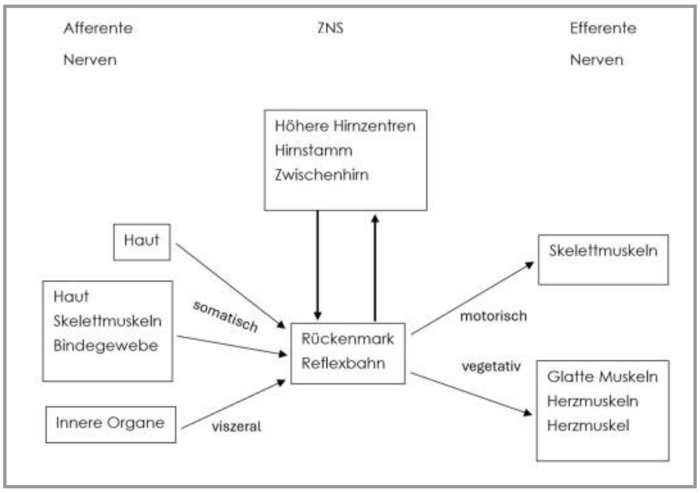
Wechselseitige Beeinflussung zwischen Bewegungsapparat, Haut und innere Organe

Diese Diplomarbeit befasst sich mit der wechselseitigen Beeinflussung zwischen Bewegungsapparat, Haut und innere Organe. Über die spinale Reflexbogen sind Reaktionen zwischen den verschiedenen Strukturen und Systemen im ganzen Körper möglich.

Aus der ganzen Komplexität des Themas wurden relevante Themen aus Anatomie und Neurologie gewählt. Es wird beschrieben, wo sich die Organe in der Brust-, Bauch- und Beckenhöhle befinden. Die Faszien spielen eine grosse Rolle im Körper, ihre Spannung bestimmt die Statik des Körpers. Sobald eine Dysbalance besteht, auf Grund Verklebungen oder erhöhte Gewebsspannung, gibt es Bewegungseinschränkungen. Die Beweglichkeit kann lokal vermindert sein, kann sich aber auch über den ganzen Körper weiter manifestieren. Zum Beispiel kann eine Störung dem Verlauf der Faszienketten folgen.

Das periphere Nervensystem wird ebenfalls kurz erläutert. Die Organe werden innerviert über das vegetative Nervensystem. Die spinalen Schaltstellen sind empfindlich für Aktivitäten von anderen Nerven im gleichen Segment. So ist es möglich, dass Störungen in den Organen in der Haut projiziert werden. Andersherum ist es auch möglich, über eine Bindegewebebehandlung der Haut eine Normalisierung der Organfunktion zu erhalten. Verbindungen gibt es zwischen allen Strukturen des Körpers.

Das Ziel dieser Arbeit ist es, die verschiedenen Wechselwirkungen zwischen den inneren Organen und dem Rest des Körpers überschaubar zu machen. Das Pferd wurde dabei als Beispiel gewählt. Deshalb gibt das letzte Kapitel eine Übersicht über die wichtigsten Erkenntnisse pro Organ, welche bei einer tierphysiotherapeutischen Behandlung mit einbezogen werden können.



Rechsteiner Claudia

Die Bedeutung der Diagonalen beim Sporthund

Der Bewegungsapparat des Hundes kann im Vergleich zum Pferd einfacher Defizite und Dysbalancen kompensieren. Er kann seine Gelenke mehr rotieren, muss keinen Reiter*in tragen und ist somit wendiger und dadurch grundsätzlich weniger verletzungsanfällig.

Die Verwendung der Hunde, welche nicht für eine Arbeit ausgebildet werden, ist sehr verschieden. Das Angebot von Sportarten ist gross und noch grösser ist die Vielfalt wie die Hundebesitzer*in ihren Hund trainieren.

Ein Tierphysiotherapeut*in entnimmt aus der Anamnese, welchen körperlichen Belastungen sein Patient*in ausgesetzt ist. Je genauer die Art und Häufigkeit der jeweiligen Bewegungsabläufe erfasst werden und je mehr Informationen man über den Trainingsinhalt und den Aufbau hat, desto eher kann der Therapeut*in einschätzen, ob eine bevorzugte Diagonale in Frage kommt und zum aktuellen Problem beiträgt oder sogar die Ursache ist.

Unter anderem begünstigen häufige, einseitige Bewegungen in Kombination mit mangelndem Ausgleich, eine Händigkeit. Die Auswirkungen auf den Bewegungsapparat fallen für das Spielbeinpaar, das Standbeinpaar und die Wirbelsäule unterschiedlich aus. Wird im Training zum Beispiel ein gezieltes sportartspezifisches «Warm up» und «Cool down» durchgeführt, kann eine funktionelle Störung des Muskel- und Faszien-Systems verhindert und ausgeglichen werden. Somit können strukturelle Veränderungen vermieden und die Entstehung weiterer Erkrankungen am Bewegungsapparat verzögert oder sogar verhindert werden.

Je intensiver und häufiger ein Hundesportler*in mit seinem/ihrem Hund trainiert, desto wichtiger ist es, dass das Wissen um die Belastungen und deren Auswirkungen in der ausgeübten Sportart vorhanden ist. Tierphysiotherapeuten*innen können Ansprechpersonen für eine gezielte Trainingsplanung sein. Damit wird die Grundlage für eine gesunde und zufriedene Sportkarriere gelegt.

Ritschard Regina

Das Lymphsystem der Katze

Eine Einteilung in MLD-relevante Territorien

Ziel der nachfolgenden Arbeit ist es, die Parallelen und Unterschiede im Lymphabflusssystem von Hund und Katze zu erarbeiten. Dabei werden folgende Fragen beantwortet: Was ist über das Lymphknotensystem der Katze bisher bekannt? Gibt es Parallelen zum Hund, welche eine Einteilung in Territorien zur Manuellen Lymphdrainage erlauben?

Anhand von Literaturrecherche wird das bisherige anatomische Wissen über das Lymphsystem des Hundes und der Katze zusammengetragen. Dabei stellt sich heraus, dass sich das Lymphsystem, obwohl in vielen Bereichen ähnlich, speziesspezifisch unterschiedlich gestaltet. Basierend auf den gewonnenen anatomischen Erkenntnissen dieser Parallelen und Unterschiede wird abschliessend ein visueller Versuch unternommen, die Katze in Territorien zur manuellen Lymphdrainage zu unterteilen. Als Vorbild dazu dient das Schema zur Einteilung des Hundes nach Dirk Berens v. Rautenfeld.

Abbildung 7: Einteilung der Katze in MLD-relevante Territorien

hellgrün:	Territorium I	mittelblau:	Territorium V
orange:	Territorium II	dunkelblau:	Territorium VI
rot:	Territorium III	hellblau:	Territorium VII
violett:	Territorium IV	dunkelgrün:	Territorium VII

Ryhiner Andrée

Evaluation von Zusammenhängen zwischen Zahnstellung beim Pferd und seiner Diagonalität

Asymmetrien im Pferdgebiss sind etwas häufiges. Diese zeigen sich zum Beispiel in Form von einseitig ausgeprägteren Wellen, Rampen oder Haken im Bereich der Backenzähne. Auch die Okklusionsebenen der Backenzähne können links und rechts verschiedene Winkel aufweisen. Solche Asymmetrien entstehen häufig aufgrund von schmerzhaften Prozessen in der Maulhöhle und können sich in Form eines Diagonalbisses auf die Schneidezähne projezieren. Aufsteigende und abfallende Diagonalbisse entwickeln sich also einerseits aufgrund von Pathologien an den Zähnen oder am Zahnhalteapparat. Weiter können Blockaden des Kiefergelenkes eine einseitig verstärkte Kautätigkeit hervorrufen; in Anlehnung an die Humanmedizin wird auch beim Pferd die craniomandibuläre Dysfunktion diskutiert.

Im Zuge meiner Ausbildung zur Tierphysiotherapeutin habe ich mich intensiver mit der Fortbewegung des Pferdes auf Diagonalen befasst. Ich habe mir deshalb die Frage gestellt, ob Diagonalbisse ebenso Projektion einer präferierten Diagonale sein könnten.

Die vorliegende Studie dient der Überprüfung dieser Hypothese. Dazu wurden sechs Pferde mit Diagonalbiss befundet. Ihre präferierte Diagonale wurde aufgrund der Inspektion in der Bewegung sowie körperlicher Daten wie Muskelprofil, Hufwinkel und Gelenksbeweglichkeit eruiert. Die aus der Anamnese erhobenen Daten wurden miteinbezogen. Es konnte ein Zusammenhang von der Seite des Diagonalbisses und der Diagonalität in der Fortbewegung festgestellt werden. Dabei handelt es sich nur um eine mögliche Tendenz, die kleine Anzahl Pferde limitiert die wissenschaftliche Signifikanz. Um die Aussagekraft zu erhöhen, müssten Folgestudien mit einer deutlich grösseren Anzahl Pferde gemacht werden.

Schmid Sarah

ECVM und ECRM

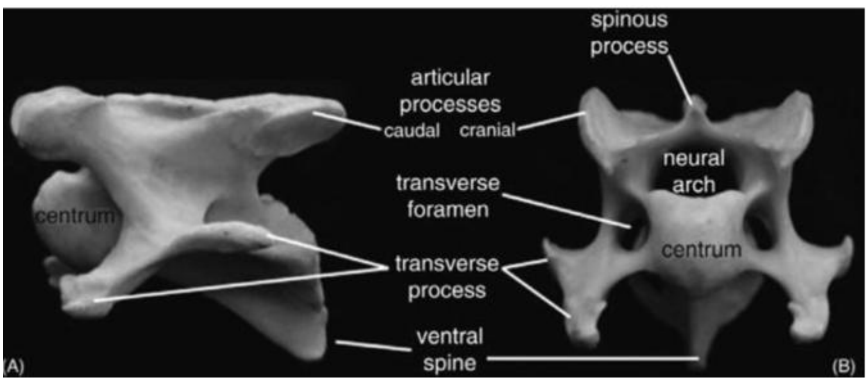
Welche Auswirkungen haben ECVM und ECRM auf die Körpersysteme
und die Dynamik des Pferdes und welche Konsequenzen hat dies f
für die aktive Therapie und das Training?

Die vorliegende Arbeit beleuchtet das relativ neue Phänomen «ECVM». Im Zentrum stehen die Auswirkungen auf die Körpersysteme und die daraus resultierenden Konsequenzen für die Therapie und das Training.

Die Auswirkungen können je nach Ausprägung und Malformation unterschiedlich sein. In den allermeisten Fällen ist die kybernetische Muskulatur betroffen. Es wird beobachtet, dass diese bei ECVM generell um ca. 30% reduziert ist. Liegen Schmerzzustände oder spinale Pathologien vor, kann es zu einer weiteren segmentalen Atrophie kommen. Die Malformationen und die kompromittierte kybernetische Muskulatur verursachen eine Instabilität des CTÜs (cervikothorakaler Übergang). Dies führt in vielen Fällen zu einer Überlastung weiterer Strukturen, namentlich der oberflächlichen Bewegungsmuskeln, der Faszien und des passiven Bewegungsapparates. Auch Auswirkungen auf die neuralen Strukturen sind möglich.

Nebst der Instabilität verursacht ECVM auch eine strukturelle Asymmetrie, welche die Pferde in eine deutliche Schiefe bringt.

Das erste Therapieziel ist Schmerzfreiheit. Danach folgt die (Re-)Aktivierung der kybernetischen Muskulatur, um den CTÜ zu stabilisieren. Im weiteren Therapie- und Trainingsverlauf werden auch die Diagonalität und Haltung verbessert, um diese Pferde langfristig gesund zu erhalten.



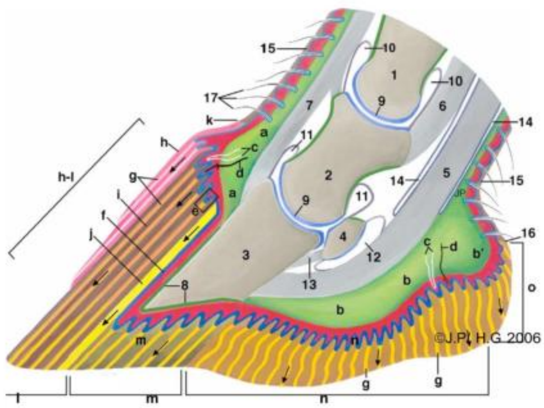
Senft Debora

Physiotherapie bei Hufrehe

Hufrehe ist eine gefürchtete Krankheit bei den Equiden. Sie kann zu erheblichen körperlichen Einschränkungen oder im schlimmsten Fall zum Tod führen. In der vorliegenden Arbeit geht es darum, die geeigneten physiotherapeutischen Massnahmen und die funktionellen Zusammenhänge im akuten und chronischen Stadium genauer zu analysieren. Ausserdem werden die wichtigsten Aspekte des Managements bei Hufrehe beleuchtet und der aktuelle Stand der Forschung im Bezug zur Hufrehe aufgezeigt.

Es gibt verschiedene Faktoren, die zu Hufrehe führen können. Durch noch nicht abschliessend geklärte pathologische Mechanismen kommt es zu einer Entzündung der Huflederhaut, weiterlaufend zu einer Rotation und teilweise einer Senkung des Hufbeines. Um betroffene Hufbereiche zu entlasten und den Schmerzen zu entfliehen, wählt das Pferd eine typische Entlastungshaltung. Diese kann zu Einschränkungen auf muskulärer, faszialer und organischer Ebene führen. Sobald das Hufbein rotiert, geht die Hufrehe in das chronische Stadium über. Das pathologisch veränderte Hornwachstum führt zur Ausbildung sogenannter Knollhufe. Durch orthopädische Beschläge wird der Stellungswinkel der Hufe verändert, was weiterlaufend Auswirkungen auf den Bewegungsapparat hat, sowohl auf struktureller als auch auf biomechanischer Ebene.

In beiden Stadien der Hufrehe gibt es physiotherapeutische Massnahmen, die den Folgen dieser Veränderungen entgegenwirken und/oder eine Verbesserung der körperlichen Befindlichkeit des Pferdes herbeiführen können. Das Management bei Hufrehe findet ein besonderes Augenmerk in der Behandlung als auch in der Prävention. Aktuelle Forschungen arbeiten daran, noch vorhandene Wissenslücken bezüglich Ätiologie und Pathologie bei der Hufrehe zu schliessen, um eine optimale Behandlung zu finden.



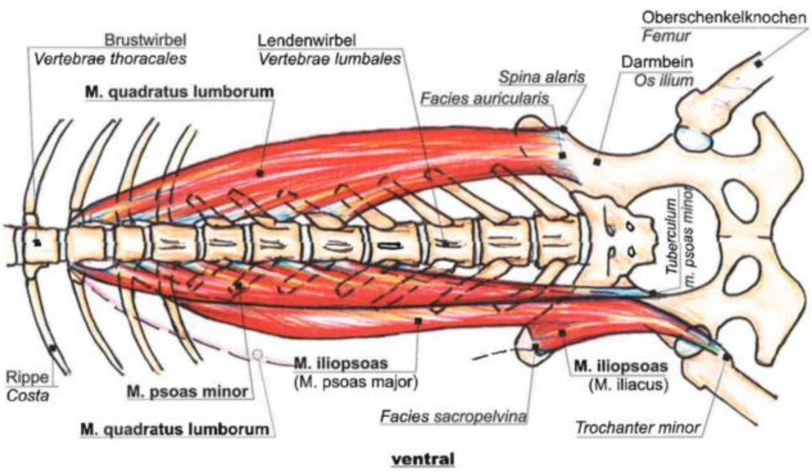
Senoner Elodie

Hypertonus de l'iliopsoas chez le chien

Quelles sont les causes sous-jacentes de la fréquente tension du muscle iliopsoas chez le chien, quelles sont ses implications biomécaniques et est-il possible d'atténuer cette tension par le biais d'exercices actifs ?

Le muscle iliopsoas est l'un des muscles sublombaires les plus puissants et les plus importants pour fléchir le membre postérieur lors de la phase oscillante de la marche et soutenir la posture du chien. Ce muscle est souvent sujet à une hypertonie et bien que des exercices d'étirement passif soient déjà pratiqués, ce muscle peut être sensible, et aucune étude n'a encore mis en évidence un exercice actif pour le traiter. L'hypertonie e schi pathologie qui peut affecter aussi bien e schiens de compagnie que e schiens athlètes, pouvant aller jusqu'à la déchirure musculaire.

Cette étude propose un exercice actif appliqué à deux chiens de compagnie présentant des symptômes d'hypertonie de l'iliopsoas et en évalue l'évolution à travers des paramètres de palpation, de mesure de l'extension de la hanche, ainsi ue par l'inspection statique et dynamique des chiens. Les résultats montrent une différence significative lors de la palpation et de l'inspection, bien qu'aucune différence significative n'ait été observée dans la mesure de l'extension de la hanche. Il est donc recommandé, pour e schiens présentant des symptômes similaires, de suivre l'exercice proposé à l'aide d'une feuille explicative et de poursuivre les recherches sur ce muscle sous-estimé par des études supplémentaires, telles que des essais contrôlés randomisés en aveugle.



Zimmerli Nils

Einfluss von TENS auf die postoperative Phase bei Hunden nach Kreuzbandriss

TENS-Behandlung durch Besitzer in der Frühphase – sinnvoll oder nicht?

Elektrotherapie gehört in der Humanphysiotherapie seit geraumer Zeit zum Behandlungsrepertoire. TENS als Anwendung bei akuten und chronischen Schmerzzuständen ist bezüglich Wirksamkeit mittlerweile gut erforscht. Gerade bei postoperativen Schmerzen ist TENS effektiv und kann zu signifikant weniger Schmerzmittelbedarf führen. Die heutigen Elektrotherapiegeräte sind mittlerweile günstig, sicher, einfach in der Handhabung und können gut in der frühen Phase nach einem Eingriff vom Patienten selber zu Hause eingesetzt werden.

In der Tierphysiotherapie findet Elektrotherapie zwar auch Verwendung, es findet sich aber wenig Literatur zum Thema. Über den postoperativen Einsatz von TENS bei Hunden als Heimbehandlung durch Besitzer existieren bisher keine Untersuchungen. Die Nachbehandlung bei Hunden nach Kreuzbandriss-Operationen in der Schweiz sieht vielerorts keine Physiotherapie in den ersten zwei Wochen nach einem solchen Eingriff vor, obschon diesbezüglich Empfehlungen erarbeitet wurden.

Diese Arbeit untersucht die Erholung in der postoperativen Phase nach Kreuzbandriss bei drei mit TENS behandelten Hunden im Vergleich zu zwei Hunden ohne Intervention. Zudem interessiert, wie gut Hunde die TENS-Behandlung tolerieren und wie BesitzerInnen die Durchführung beurteilen. Anhand einer ausgearbeiteten Testsammlung wird die Erholung der Hunde präoperativ und nach der Fadenentfernung eingeschätzt. Durch die mit fünf Tieren geringe Probandenzahl können bezüglich der Fragestellung keine klaren Aussagen gemacht werden. Die TENS-Behandlung kann bei zwei von drei Hunden gut durchgeführt werden und ist für die Besitzer problemlos anwendbar. Weitere Untersuchungen sind nötig, um TENS als Heimbehandlung durch Besitzer in der frühen Rehabilitation optimal einsetzen zu können.

Kreuzbandruptur Hund – Operation - Technik TTA (Tibial Tuberosity Advancement)

Ein Fallbeispiel mit Schritt für Schritt Darstellung der Operationstechnik

Eine sehr oft auftretende Verletzung ist der Riss des vorderen Kreuzbandes beim Hund.

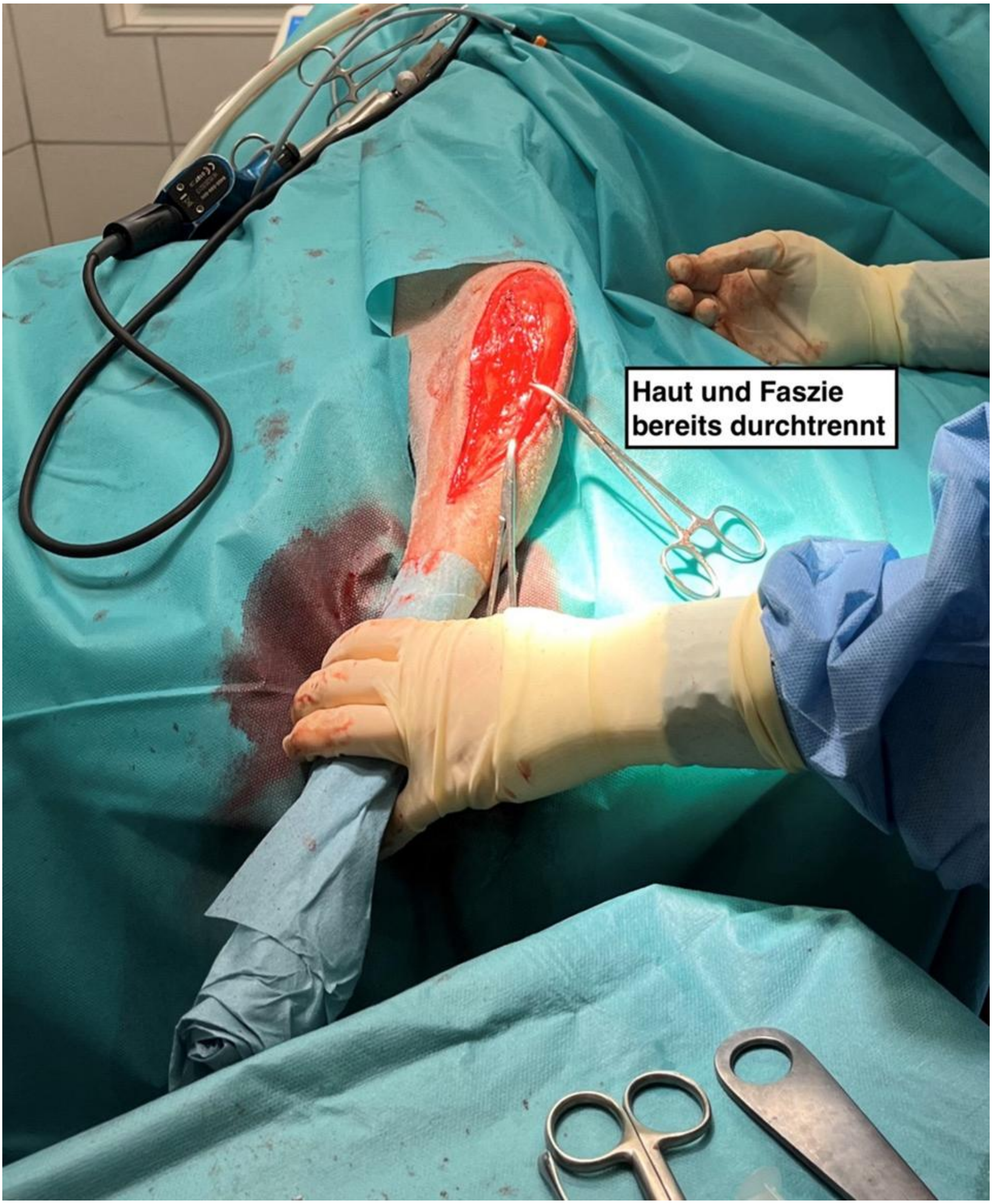
Im Gegensatz zum Menschen reisst das Kreuzband beim Hund äusserst selten durch einen Unfall. Darum wird der Kreuzbandriss beim Hund als Erkrankung eingestuft. Es gibt auch selten eine isolierte Meniskusverletzung ohne Totalruptur des Kreuzbands. Meistens passieren Teilrupturen von denen sich die Hunde oft gut erholen bevor es zum vollständigen Riss kommt. Ursache ist eine steile Stellung der Hinterhand und dadurch eine erhöhte Belastung des vorderen Kreuzbandes bei jedem Schritt. Ein breites Becken verursacht dazu mehr Rotation und dadurch erfährt das Knie mehr Scherkräfte. So kommt es zu einer Abnutzung und zu Teilrissen bis zur vollständigen Ruptur.

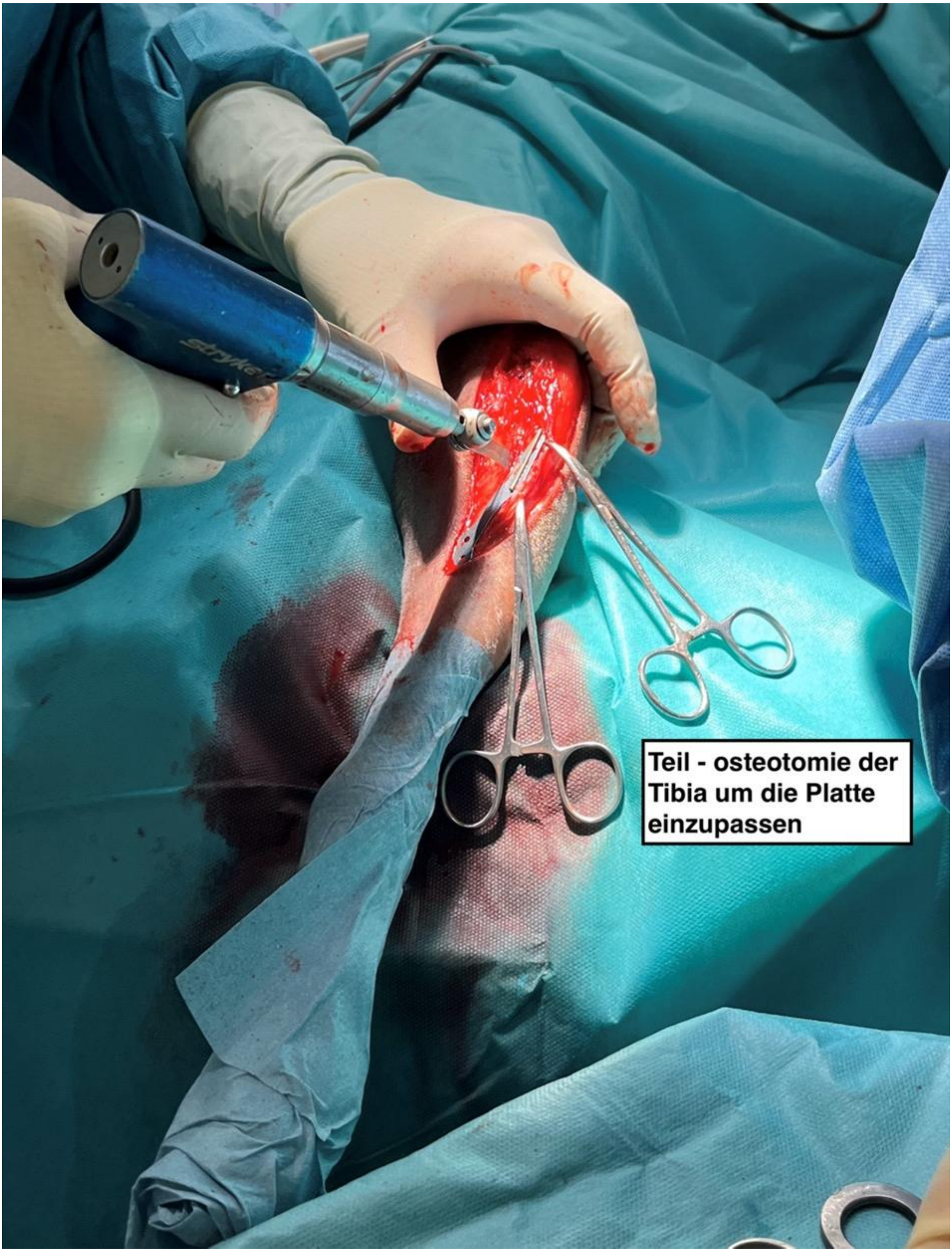
Dies ist fast immer eine Indikation für eine Operation. Das Ziel der Operation ist die biomechanische Situation zu verändern und so zu verbessern, dass das Knie durch die veränderte biomechanische Stellung wieder stabil wird. Es gibt unterschiedliche Methoden.

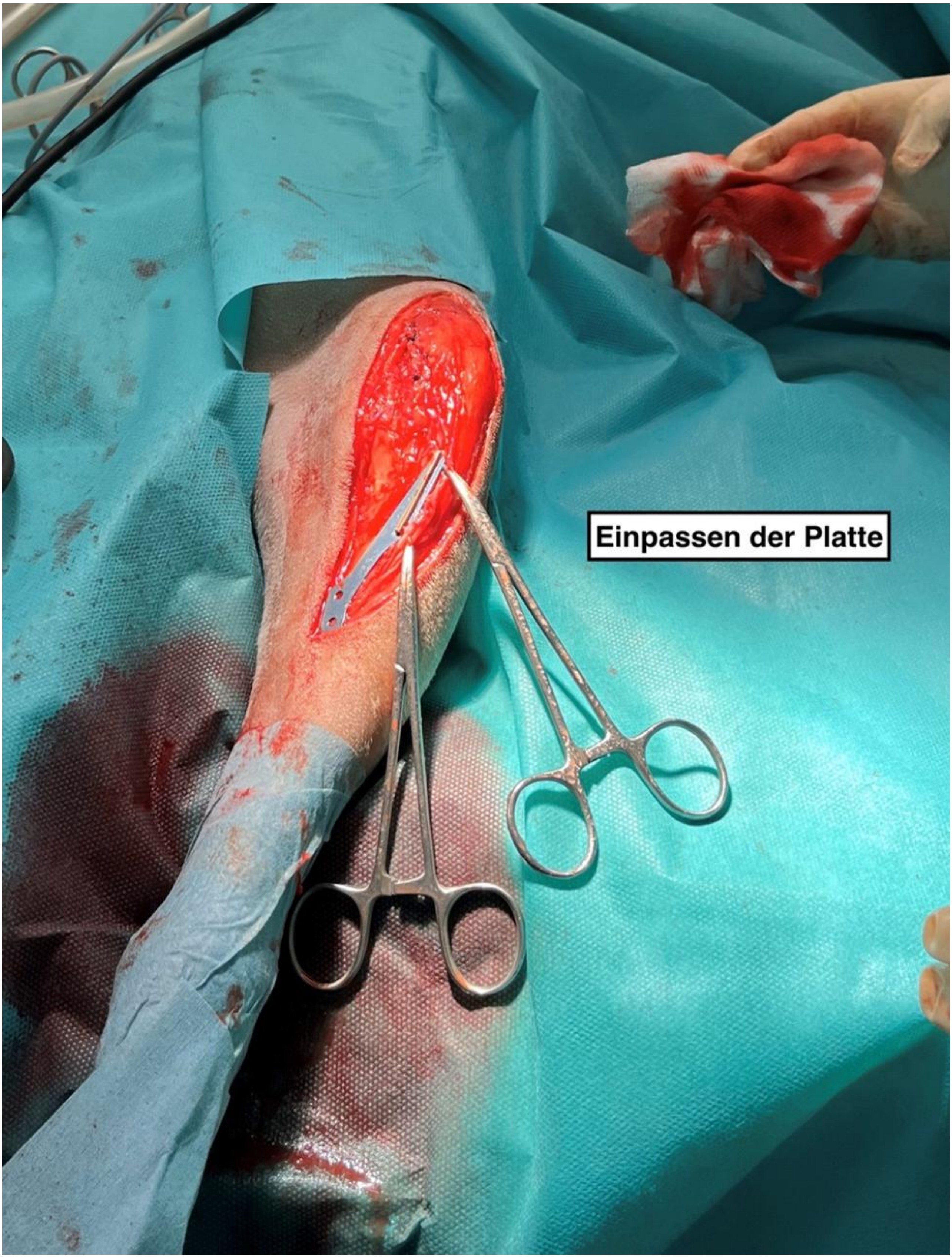
Die gängigsten sind:

* TTA: Tibial Tuberosity Advancement (wurde in diesem Fallbeispiel durchgeführt)
* TPLO: Tibia Plateau Leveling Osteotomy

Kreuzbandruptur Hund – Operation - Technik TTA (Tibial Tuberosity Advancement)



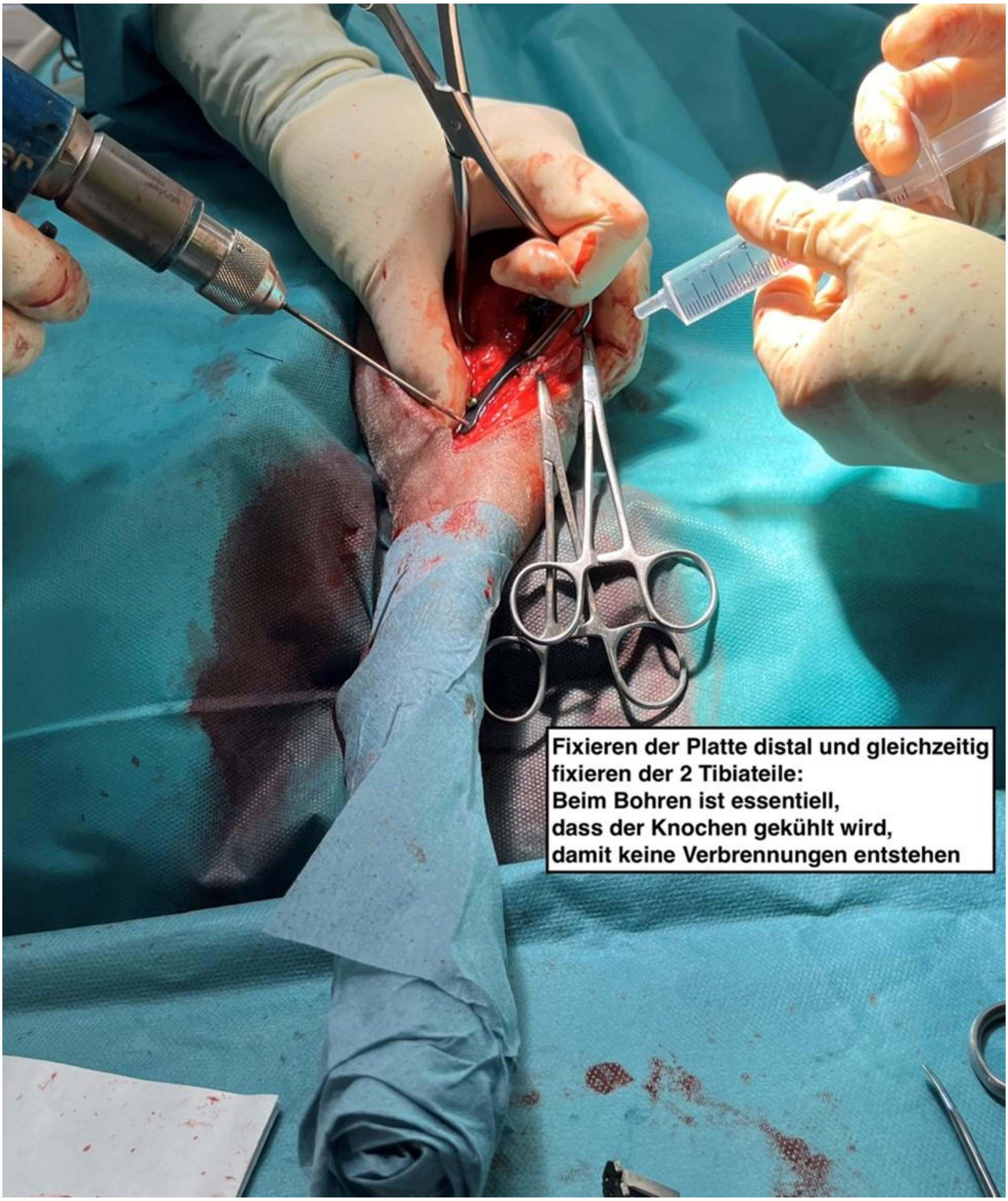

stryker
Teil - osteotomie der Tibia um die Platte einzupassen

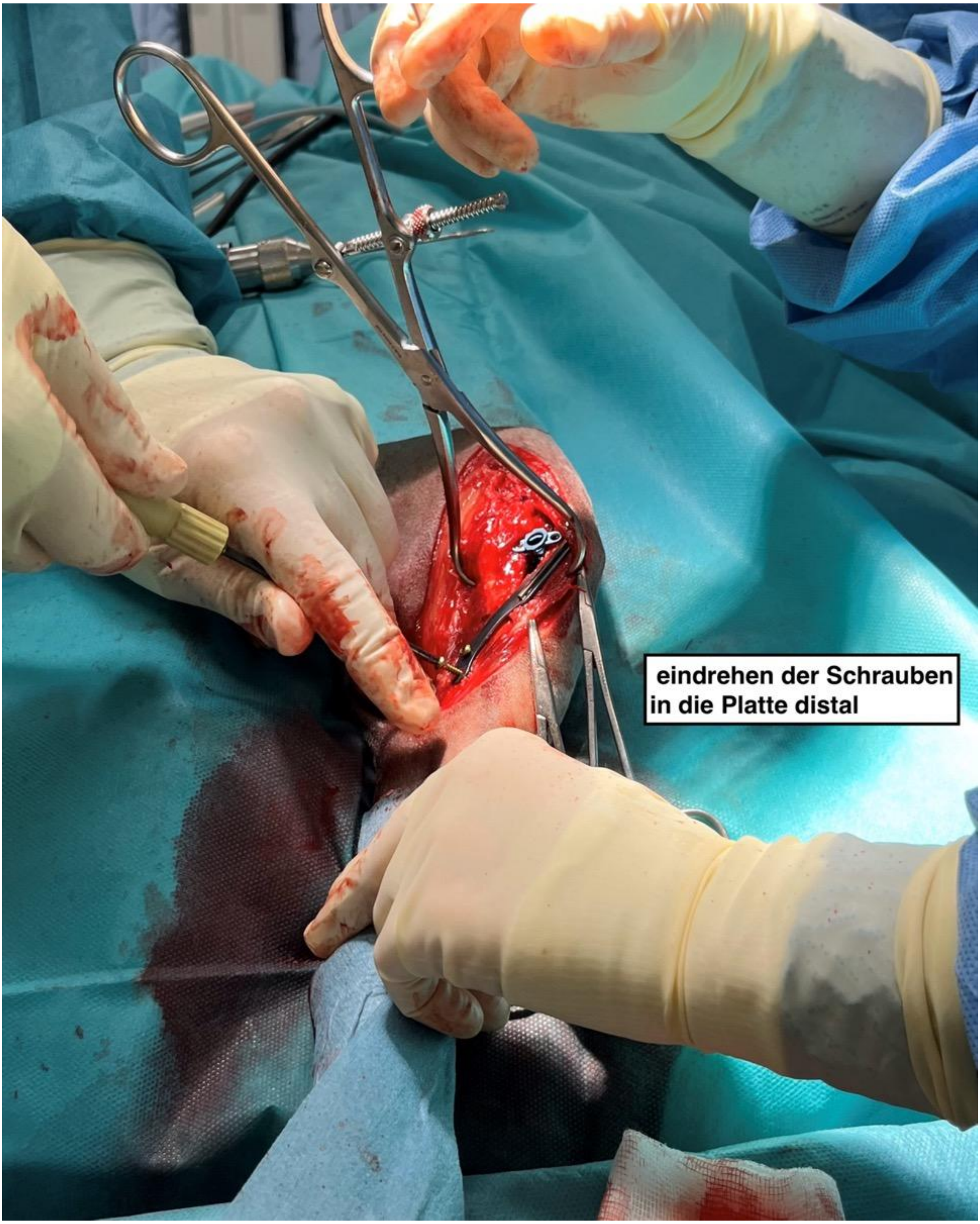


Verband für Tierphysiotherapie - Kreuzbandruptur Hund – Operation - Technik TTA


Platte ist proximal bereits fixiert.
Nun kann die Osteotomie vollständig
ausgeführt werden und der
Teil der Tibia abgespreizt werden um
den Abstandhalter einzufügen
stryker


eingefügter Abstandhalter
und gut sitzende Platte:
wichtig ist, dass die Platte
distal noch gut auf die Tibia
zu liegen kommt


Fixieren der Platte distal und gleichzeitig
fixieren der 2 Tibiateile:
Beim Bohren ist essentiell,
dass der Knochen gekühlt wird,
damit keine Verbrennungen entstehen


eindrehen der Schrauben
in die Platte distal


fixierte Platte und Abstandhalter
nun wird der Spalt noch mit
Spongiosa aufgefüllt


Nähen / Verschliessen der Faszie, die geschnitten werden musste um Zugang zum Knochen zu haben. Dieser Schritt ist enorm wichtig für eine gute funktionelle Regeneration. Wird die Faszie nicht einzeln verschlossen, kann es zu Nahtdehiszenz kommen durch zuviel Spannung


Verschluss der inneren
Hautschichten


innerer Verschluss mit
selbstauflösenden Fäden


abschliessende Hautnaht mit Fäden,
die 10 Tage nach OP gezogen werden

3. internationaler hybrider Kongress
05. - 07. Juni 2026

Die Planungs- und Vorbereitungsarbeiten für den 3. Internationalen Kongress laufen auf Hochtouren.

Wir konnten bereits einige hochkarätige Referenten verpflichten.

Das Programm wird ähnlich aufgebaut sein wie letztes Jahr:
Freitag und Samstag am Vormittag Input Referate und am Nachmittag Workshops um die Themen zu vertiefen.

Es wird wiederum Pferd und Kleintier parallel laufen.

Der Veranstaltungsort ist dieses Mal der **Horse Park Zürich – Dielsdorf**.

Der Sonntag wird ein gemeinsamer Tag: Dr.Maja Guldborg aus Dänemark, absolute Spezialistin in funktioneller Neurologie, wird uns die neben der funktionellen Neurologie die Neurorehabilitation in Theorie und Praxis näher bringen.

Ein Highlight der besonderen Art findet am Samstagabend statt:

Gillian Higgins, Horses Inside Out wird ihre legendäre Show mit 2 bemalten Pferden zeigen und die Biomechanik live erörtern.

Nicht verpassen, reserviert euch den Termin bereits jetzt!

Mehr Information findet ihr auf der Webseite **https://svtpt-tierphysio-congress.ch** und in den nachfolgenden Sponsorendokumenten.

Falls ihr mögliche Sponsoren kennt, meldet euch bitte direkt bei Isabelle Gysi, **gf@svtpt.ch.**

Selbstverständlich ist es auch möglich, dass ihr eure eigenen Leute ansprecht und die Sponsorenmappe abgeben könnt.

Es gibt auch einen elektronischen Flyer und zu einem späteren Zeitpunkt Plakate, die ihr euren Kunden abgeben und in Reitvereinen / Reitschulen etc. verteilen und aufhängen könnt.

SVTPT
FSPA
FSFA
FSFB

SCHWEIZERISCHER VERBAND FÜR TIERPHYSIOTHERAPIE
FÉDÉRATION SUISSE DE PHYSIOTHÉRAPIE POUR ANIMAUX
FEDERAZIONE SVIZZERA DELLA FISIOTERAPIA PER ANIMALI
FEDERAZIUN SVIZRA DELLA FISIOTERAPIA PER BES-CHAS

Geschätzte Tierärztinnen und Tierärzte, werte Kolleginnen und Kollegen, liebe Freunde,

Im Namen des Schweizerischen Verbands für Tierphysiotherapie (SVTPT) möchten wir Sie auf unseren bevorstehenden «3. internationalen Tierphysiotherapie Kongress» vom **5. – 7. Juni 2026** aufmerksam machen. Die Veranstaltung findet im Horse Park in Zürich - Dielsdorf statt und richtet sich an Tierphysiotherapeut/innen, Tierärzt/innen, Health Professionals, Freunde und Förderer unseres Verbands und interessierte Tierhalter/innen.

Es freut uns sehr, euch die ersten hochkarätigen Referenten bzw.
Workshops ankündigen zu dürfen.

**Dr. Maja Guldborg,
DK**

**Sophie Hargreaves
NZ, PT**

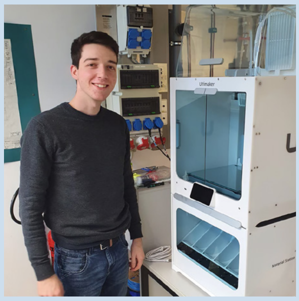
**Gillian Higgins GB
BSc, BHS Senior
Coach**

**Dr. Heli Hyytiäinen
FI**

**Dr. med.vet.
Leena Inkilä
FI**

**Dr. Russell
MacKechnie-Guire
GB**

**Dr. Jenny Moe,
USA, PT, MS, DPT,
CCRT, APT(NV)**



**Pawsthesis DE
Orthopädietechnik
für Tiere aus dem
3D-Druck**

Die Fortbildung kann von Tierärztinnen und Tierärzten über die GST mit Bildungspunkten und von Tierphysiotherapeuten über WB Tage über den SVTPT angerechnet werden.

Wir freuen uns sehr, viele bekannte und neue Gesichter zum fachlichen Austausch und ungezwungenen Networking bei uns begrüßen zu dürfen. Bitte merken Sie sich das Datum vor, und besuchen Sie unsere spannende Poster-Ausstellung und den interessanten Sponsoren- und Aussteller Bereich, sowie entdecken Sie ein köstliches Catering.

Als **Sponsor** für die Veranstaltung, finden Sie im Anhang weitere Informationen über die Konditionen.

Mit herzlichen Grüßen
Schweizerischer Verband für Tierphysiotherapie SVTPT

B. Stebler

Brigitte Stebler
Präsidentin

Bereits verpflichtete Referierende

<table>
<tr>
<td>Dr. Maja Guldborg, DK</td>
<td>
Dr. Maja Guldborg schloss 1996 ihr Studium der Tiermedizin an der Königlichen Dänischen Veterinär- und Landwirtschaftsuniversität ab. Sie war bis 2004 in einer Pferdepraxis tätig und führte orthopädische Untersuchungen und Behandlungen durch.

Im Jahr 2001 absolvierte sie die internationale Akupunkturausbildung und wurde von der IVAS (International Veterinary Acupuncture Society) in Helsinki zertifiziert. 2003-4 wurde sie in Veterinärchiropraktik ausgebildet und von der IVCA (International Veterinary Chiropractic Association) und der IAVC (International Academy of Veterinary Chiropractic) zertifiziert.

2005-7 absolvierte sie ein Masterstudium in SMT (spinal manipulative therapy) und funktioneller Neurologie am [HOWC.edu](http://howc.edu/) in Wisconsin.

2009 - jetzt hat sie auch die folgenden Module vom Carrick Institute, Florida und IAFNR absolviert;

· Funktionelle Neurologie 200
· Klinische Neurowissenschaften 801-825
· Funktionelle Neurologie-Seminare
· Rezeptorbasierte Grundlagen, RBE
· Pain Reset und Dysautonomia-Programm, das die Grundlage für die Erlangung von bestandenen Prüfungen und Fellowships in den 2 höchsten humanen Ausbildungen in funktioneller Neurologie gebildet hat.

2020: FIBFN (Fellow International Board Functional Neurology)

2021: FACFN (Fellow American Chiropractic Functional Neurology)

Seit 2004 führt sie ihre eigene Praxis, in der sie funktionell neurologisch mit Chiropraktik und Neuro-Rehabilitation arbeitet. Es ist nicht möglich, mit einem Körper zu arbeiten, als wäre er ein Auto... alles ist miteinander verbunden und über das Nervensystem verknüpft. Wenn es über einen langen Zeitraum hinweg kompensiert hat, kann nichts schnell wiederhergestellt werden. Es reicht nicht aus, ein entzündetes Gelenk zu behandeln, wenn die Ursache der Entzündung weiter besteht. Je besser wir die zugrunde liegenden neurologischen Zusammenhänge verstehen, desto besser können wir die korrekte Funktion des Einzelnen optimieren und stärken.

Zusätzlich ist sie zertifizierte Mentaltrainerin, ein kognitives Training, das darauf abzielt, das Bewusstsein des Besitzers zu stärken, denn die Psyche des Besitzers hat einen großen Einfluss auf die Psyche unserer Tiere.

Je mehr wir wissen, desto mehr wissen wir, dass wir nicht wissen...
https://www.majaguldborg.dk
</td>
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Sophie Hargreaves NZ	Sophie stammt ursprünglich aus Großbritannien und kam 1984 nach Neuseeland. 1990 schloss sie ihr Studium der Humanphysiotherapie an der Otago University ab und absolvierte ein Jahr später in Großbritannien eine Weiterbildung zur Pferdephysiotherapeutin. Sie bildet sich weiterhin für Pferde und Menschen aus, um ihr Wissen und ihre Fähigkeiten auf dem neuesten Stand zu halten, unter anderem durch Training mit Lindsay Wilcox-Reid in Equipilates™. Sophie ist eine registrierte Trainerin für Advanced Equipilates™ Biomechanik und leitet regelmäßig Kurse auf dem Pferd und zu Fuss. Ihr Wissen in Physiotherapie und Biomechanik kombiniert sie mit ihrer Liebe zur Bewegungsanalyse. So nutzt sie ihre über 40-jährige persönliche Erfahrung im Pferdesport und ihr professionelles Wissen in der Pferdephysiotherapie, um der Pferdegemeinschaft einen einzigartigen Service zu bieten. Wenn Sophie nicht gerade Lehrvorträge für Gruppen wie Pony- und Reitclubs hält oder professionelle Schulungen für Jockey-Lehrlinge durchführt, behandelt sie verletzte Reiter und deren Pferde und leitet Gruppen-Physiotherapie-/Pilates-Sitzungen im Sattelstand, um die Leistung und das Bewusstsein der Reiter zu verbessern. Sophie ist außerdem Para-Klassifizierungsbeauftragte bei ESNZ. **https://www.equipilates.com/sophie-hargreaves.html**
Gillian Higgins GB BSc, BHS Senior Coach, Dip (RM) MSM, ITEC (equine), MCAM, MIAS, MRAMP	Gillian ist eine der weltweit führenden Pädagoginnen für Pferdeanatomie und Biomechanik. Ihre Arbeit hat das Leben von Tausenden von Pferden verbessert und sie inspiriert Reiter aus allen Disziplinen. Gillian hat eine Leidenschaft für Pferde, die Anatomie von Pferden und teilt alles, was sie weiß, zum Wohle des Pferdes. Eine Autorität in der Anatomie und Biomechanik von Pferden, Senior Coach der British Horse Society, professioneller Sport- und Heiltherapeut, Autor und mit einem erstklassigen Abschluss in Pferdewissenschaften und Unternehmensführung. Gillian ist spezialisiert auf die Beurteilung von Haltung und Bewegung, entwickelt Übungen zur Leistungssteigerung und schult Pferdebesitzer. Sie ist bekannt für ihre anatomische Malerei an lebenden Pferden, die sie für ihren Unterricht verwendet. 1. Weltweit führende Pädagogin für Pferdeanatomie und Biomechanik 2. Spezialistin für Haltungs- und Bewegungstherapie 3. Revolutionärere anatomische Künstlerin für Pferde 4. HIO in 23 Ländern auf 5 Kontinenten präsentiert 5. Übergab HIO an die Königin 6. Autorin von 11 Büchern, die in 12 verschiedene Sprachen übersetzt wurden 7. Verdienstauszeichnung der BHS 8. Nahm an Wettkämpfen auf S-Niveau in der Vielseitigkeit teil 9. Vertrat GB als Fahrschülerin und als internationale Vielseitigkeitsreiterin 10. Organisatorin von weltweit führenden Konferenzen zur Pferdewissenschaft 11. Kuratorin einer erfolgreichen Ausstellung für anatomische Kunst von Pferden 12. Pferdetherapeutin für olympische und 5* Pferdereiter 13. Ausbildung in allen Reitsportdisziplinen auf allen Niveaus 14. Wurde in allen führenden britischen Zeitschriften und in der internationalen Presse vorgestellt Wenn Sie weitere Informationen wünschen, gehen Sie bitte auf **https://www.horsesinsideout.com/about-gillian**

Dr. Heli Hyytiäinen FI	Heli schloss im Januar 2000 Physiotherapie – Studium ab und absolvierte 2003 ihre finnische Spezialisierung in Tierphysiotherapie. Seither arbeitet sie ausschließlich mit tierischen Patienten. Im Jahr 2012 machte sie ihren Master of Science in Veterinärphysiotherapie an der Königlichen Tierärztlichen Hochschule und schloss 2015 ihre Promotion ab. Vor 17 Jahren gründete sie die Abteilung für Physiotherapie am Helsinki University Veterinary Teaching Hospital und hat sie seitdem weiter ausgebaut, wobei sie sowohl mit Kleintieren als auch mit Pferden arbeitet. Außerdem ist sie beratende Physiotherapeutin für eine private Pferdeklinik. Derzeit arbeitet sie als klinische Dozentin an der Fakultät für Veterinärmedizin der Universität Helsinki. Sie ist Leiterin der Forschungsgruppe FaunaFysio, die Forschung und evidenzbasierte Informationen für die Tierphysiotherapiegemeinschaft bereitstellt. Außerdem ist sie Dozentin am Master of Science in Veterinärphysiotherapie der Universität Liverpool. **https://researchportal.helsinki.fi/en/**
Dr. med.vet. Leena Inkilä FI DVM, PhD	Leena Inkilä schloss ihr Studium 2019 an der Universität Helsinki ab und promovierte dort 2025 zu Verletzungen und Biomechanik bei Agility-Hunden. Ihre Forschung befasst sich mit Trainingsroutinen, Verletzungen und der Sprungbiomechanik bei Agility-Hunden. Sie entwickelt leidenschaftlich gerne Werkzeuge und Methoden, um Verletzungen zu reduzieren und das Wohlbefinden von Hundesportlern zu verbessern. **https://researchportal.helsinki.fi/en/**
Dr. Russell MacKechnie-Guire GB	Russell MacKechnie-Guire hat einen Doktortitel in Pferdebiomechanik, den er 2019 am Royal Veterinary College erworben hat. Russells Dissertation trägt den Titel «The Relationship between Saddle and Rider Kinematics, Equine Locomotion, and Thoracolumbar Pressures in Sports Horses». Russell ist bei Centaur Biomechanics tätig, einem Unternehmen, das er 2006 gegründet hat. Er hat die Auswirkungen von Sattel, Zaumzeug und Sattelgurt sowie des Reiters auf die Gesundheit und Leistung von Pferden eingehend erforscht. Russell hat eine Stelle an der Hartpury University als Dozent für Pferdebiomechanik inne. Russells derzeitiges Forschungsgebiet ist die Interaktion zwischen Pferd und Reiter, die Wirbelsäulenkinematik bei Pferden, wenn sie über den Boden geritten werden, die Auswirkung der Asymmetrie des Reiters auf die Rückenbewegung des Pferdes und - aus der Perspektive der Rehabilitation - die Auswirkung von Trainingshilfen und Stangenarbeit auf die Rückenbewegung. Darüber hinaus arbeitet Russell mit Forschern an verschiedenen Forschungsprojekten im Zusammenhang mit der Gesundheit, Rehabilitation und Leistung von Pferden zusammen. Russell ist Berater für das Programm World Class, Team GBR des britischen Reitsportverbands und Mitglied der wissenschaftlichen Beratergruppe des Team GBR. Russell ist außerdem Mitglied der wissenschaftlichen Beratungsgruppe der Society of Master Saddlers und gehört dem Exekutivausschuss der International Task Force on Laterality in Sports Horses an. Russell ist außerdem Pilates-Lehrer, Intrinsic (Human) Biomechanics Trainer, BHSI-Pferdetrainer und ein begeisterter Wettkämpfer in Dressur und Springen. **https://www.centaurbiomechanics.co.uk**

Dr. Jenny Moe, PT, MS, DPT, CCRT, APT(NV) USA	Dr. Jenny Moe ist seit 20 Jahren staatlich anerkannte Physiotherapeutin und hat vor 13 Jahren ihr Diplom in Hunderehabilitation am Canine Rehabilitation Institute erworben. 2009 gab Moe die Pädiatrie auf, um in einer vielbeschäftigten Fachtierarztpraxis in der San Francisco Bay Area (SAGE Veterinary Centers) zu arbeiten, wo sie die Rehabilitationspraxis auf zwei Standorte ausweitete. 2018 eröffnete sie eine weitere Praxis (Pawesome PT) in der Gegend von South Lake Tahoe, bevor sie 2020 nach San Francisco zurückkehrte. Dr. Moe konzentriert sich nun auf eine mobile Praxis für manuelle Therapie und Doggon' Wheels in der Gegend von San Francisco. Dr. Moe freut sich, ihre Liebe zu Hilfsmitteln, älteren Haustieren und kreativen Lösungen mit dem Geschäft zu verbinden. Sie klärt die Veterinärwelt und die Öffentlichkeit leidenschaftlich gerne über die Vorteile des frühzeitigen Einsatzes von Rädern für eine Vielzahl von Patienten auf und möchte mit dem Glauben aufräumen, dass Räder „das Ende der Fahnenstange/der letzte Ausweg" seien. **www.doggon.com**
Pawsthesis DE	Pawsthesis ist ein Hersteller von orthopädischen Hilfsmitteln für Tiere. Der Fokus liegt hierbei auf der individuellen Fertigung von Orthesen, Voll- und Teilprothesen. Hierfür wird auf das technische Potential von additiver Fertigung und 3D-Scanning gesetzt. Innovation und Entwicklung ist ein Kernfaktor bei Pawsthesis. So werden alle Prothesen mit den in Haus entwickelten Gelenken und Federungssystemen ausgestattet. Die Orthesen verfügen über das eigens designte ROM-Gelenk (Range of Motion). So sind sowohl temporäre Behandlungen (postoperative Maßnahme), langfristige Behandlungen und bedarfsgerechte Belastungssteuerung möglich. Dank Pawsthesis sind in der Versorgung von Tieren neue Wege möglich! **https://www.pawsthesis.de/**

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SVTPT
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SCHWEIZERISCHER VERBAND FÜR TIERPHYSIOTHERAPIE
FÉDÉRATION SUISSE DE PHYSIOTHÉRAPIE POUR ANIMAUX
FEDERAZIONE SVIZZERA DELLA FISIOTERAPIA PER ANIMALI
FEDERAZIUN SVIZRA DELLA FISIOTERAPIA PER BES-CHAS

Pferde erleben wie nie zuvor

Exklusives VIP-Erlebnis beim SVTPT-Kongress 2026

Der perfekte Teamanlass, Firmenevent oder die Geburtstagsfeier könnte so aussehen: Ihre Gäste stehen fasziniert vor zwei lebenden Pferden; eines bemalt mit präziser Muskulatur, das andere mit dem kompletten Skelett. Gillian Higgins, eine der weltweit führenden Expertinnen für Pferdeanatomie, erklärt live die Geheimnisse der Biomechanik in Bewegung.

Gillian Higgins ist besonders:

- Weltweite Anerkennung: Präsentierte bereits vor der britischen Königin
- Einzigartige Methode: Anatomische Bemalung lebender Pferde
- Faszinierende Show: Biomechanik an der Longe, unter dem Sattel und beim Sprung
- Für jeden verständlich: Komplexe Wissenschaft spannend erklärt

Save the date:

Hybrid-Kongress am **5.-7. Juni 2026**

mit dem VIP-Erlebnis am **Sa, 6. Juni 2026** «HORSES INSIDE OUT» - Abendshow im Horse Park Zürich-Dielsdorf Samstag Abend

Kongress-Sprache: **Englisch**

Gold-Sponsoren erhalten VIP-Zugang zur spektakulären Abendshow.

Was Sie erwartet als VIP:

- Exklusive Live-Demonstration mit anatomisch bemalten Pferden
- Einblicke in die Geheimnisse der Pferdebewegung
- Networking in stilvollem Ambiente
- VIP-Betreuung und Apéro
- Unvergessliches Erlebnis für alle Teilnehmer

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CIRS: Critical Incident Reporting System

Als Critical Incident Reporting System, kurz CIRS, bezeichnet man Berichterstattungssysteme zur anonymen Meldung von kritischen Ereignissen (critical incident) oder auch Beinahe-Fehlern (near miss) in Einrichtungen des Gesundheitswesens und der Luftfahrt. Es ist ein „Fehlerberichts- und Lernsystem“

Mit Hilfe des 3Be-Systems (Berichten – Bearbeiten – Beheben) können erkannte Risiken bearbeitet werden, um so aus den identifizierten kritischen Situationen und Risiken Strategien zur Vermeidung und Handhabung zu entwickeln und umzusetzen. Da sich die aus dem 3Be-System entwickelten Verbesserungsmaßnahmen an den realen Gegebenheiten vor Ort orientieren, kann so ein Risikomanagement individuellen Zuschnitts entstehen, das den Bedürfnissen des eigenen Hauses Rechnung trägt und dabei noch kostengünstig, ressourceneffizient und -effektiv ist.

Ist ein Zwischenfall aufgetreten, so gilt es primär, die folgenden drei Fragen zu erörtern:

1. Ist eine relevante und möglicherweise bleibende Schädigung einer Patientin/ eines Patienten aufgetreten?
2. Handelt es sich um einen meldepflichtigen Fall?
3. Könnte sich ein derartiger Zwischenfall potenziell wiederholen – in der eigenen Praxis, in der engeren Region oder überregional?

"CIRS – aus Fehlern lernen"

Das Ziel des Meldesystems ist, dass Kolleginnen und Kollegen von Missgeschicken, die einzelnen unterlaufen sind, lernen können. CIRS soll auch für Lernprozesse und zur Qualitätssicherung breit genutzt werden können. So sollen Zwischenfälle auch in Qualitätszirkeln besprochen werden. Die Analyse der Zwischenfälle führt zu einem übergeordneten Lerneffekt und soll einen Qualitätsverbesserungszyklus anstossen.

Alle interessierten Kolleginnen und Kollegen und insbesondere Moderator/-innen von Qualitätszirkeln sind gebeten, regelmässig exemplarische Fälle einzugeben, damit das CIRS wachsen kann. Die Fälle können an die Geschäftsführung, Isabelle Gysi gf@svtptp.ch eingegeben werden und werden dann anonym auf der Webseite unter https://svtpt.ch/?cmspid=2136&changeLanguage=de&qgCms_editmode=0 aufgeschaltet. Es ist kein an den Pranger stellen, sondern gemeinsam lernen und uns verbessern.

Zwischenfälle können in verschiedene Gebiete eingeteilt werden:

1. Diagnostik: z.B. übersehen eines wichtigen Hinweises, Flagkonzept nicht oder unvollständig beachtet.
2. Therapie: z.B. inkorrekte Dosierung, Interaktion verschiedener Behandlunsgmassnahmen oder Therapien übersehen / missachtet; langer ausbleibender Therapieerfolg nicht beachtet
3. Kommunikation: z.B. indirekte Kommunikation, die Fehler hervorruft; Therapieziele ungenau kommuniziert, Therapieabfolge unklar kommuniziert; ungeeigneter Kommunikationskanal gewählt; unerwartete / schwierige Kommunikation mit Besitzer oder Zuweiser etc. Missverständnis in der Kommunikation.
4. Organisation: z.B. Fehlplanung in der Route; Missachten von möglichem hohen Verkehrsaufkommen; zu dichte Planung; Dringlichkeit des Falles falsch eingeschätzt; Fehler nicht erkannt, nicht kommuniziert.

Was suchen wir?

Behandlungs- / Erfahrungskurzberichte mit dem Ziel:

Aus Fehlern anderer Therapierender lernen, ohne die Erfahrung selbst machen zu müssen. Oder andersrum, seine eigenen Erfahrungen Aufarbeiten und mit anderen Therapierenden teilen und so vor potenziellen Gefahren warnen. Ein freier Erfahrungsaustausch von Therapeuten für Therapeuten.
Schlussendlich soll ein übergeordneter Lerneffekt und ein Qualitätsverbesserungszyklus angestossen werden.

Beispiele:

Therapie:

Dem Tierphysiotherapeuten wird ein Pferd mit einer Beugesehnenproblematik vorgestellt. Der Besitzer ist sehr interessiert möglichst viel selber zu machen und scheint fast übermotiviert, um sein Pferd so schnell wie möglich wieder einsatzbereit zu haben.
Der Tierphysiotherapeut entscheidet sich zusätzlich zu seinen Behandlungen in der Zwischenzeit dem Besitzer manuelle Handgriffe zu instruieren und eine Lasertherapie gleichzeitig anzuwenden, die der Besitzer gemäss Instruktion selber ausführen kann. Der Besitzer wird gründlich instruiert und auch über die Dosierung informiert.

Bei der nächsten Behandlung ist das Bein deutlich mehr geschwollen als bei der letzten Sitzung. Der Tierphysiotherapeut versucht zu evaluieren warum die Schwellung zugenommen und nicht wie erwartet abgenommen hat. Nachdem alles Mögliche als Auslöser ausgeschlossen wurde, fragt der Therapeut nochmals genau nach wie die Lasertherapie ausgeführt wird. Der übermotivierte Besitzer dachte, je mehr desto besser und hat statt der angeleiteten einmal täglichen Behandlung, die Lasertherapie 3-mal am Tag durchgeführt, was zu einer Überreizung der Strukturen geführt hat.

Lerneffekt:

Bei der Instruktion des Besitzers bezüglich Ausführung von therapeutischen Handgriffen oder apparativen Massnahmen genau darauf achten, dass wir die Dosierung erklären und auch die Folgen einer Über- bzw. Unterschreitung dieser erklären.

Kommunikation:

Ein Pferd wird dem Therapeuten überwiesen, um Rückenverspannungen zu lösen. Das Pferd hat eine distale Problematik am Fesselgelenk hinten rechts. Für den Tierarzt ist das das zu behandelnde primäre Problem und die Rückenprobleme eher sekundär. Der Besitzer diskutiert während der Behandlung mit dem Therapeuten, was er über die Problematik denkt. Es werden Meinungen ausgetauscht und dabei fällt auch die Aussage, dass es allenfalls auch möglich ist, dass die Rückenverspannung und eigeschränkte Beweglichkeit schon länger besteht und so das distale Problem begünstigt hat.

Der Besitzer (eine etwas «heikle» Person gemäss TA) hat anschliessend mit dem TA gesprochen und gesagt, dass der Therapeut gesagt hätte, dass das Rückenproblem sicher primär sei. Dabei hat der Besitzer auch seine Interpretationen dazu eingefügt. Worauf es eine Diskussion TA-Therapeut gab mit dem Fazit, dass beide dasselbe sagen sollten, um beim Besitzer glaubhaft zu bleiben.

Lerneffekt:

Bei unterschiedlichen Ansichten bezüglich Ursache / Verhalten des Problems Immer möglichst unverzüglich nach der Behandlung das Gespräch mit dem TA suchen und mit ihm Besprechen, bevor der Besitzer selber mit seiner Variante an den TA gelangt.

Kommunikation:

Die Hundetrainerin, welche einen Hund mit einer unklaren Diagnose aber klar sichtbaren Gangproblemen in Bezug auf eine Verhaltensproblematik im Training hat, empfiehlt der Besitzerin eine physiotherapeutische Behandlung. Da der Hund eine unklare Vergangenheit hat und viele Alltagssituationen noch stressig sind, wird von der Hundetrainerin nach Rücksprache mit der Besitzerin ein Termin zu dritt festgelegt, damit die Trainerin die Besitzerin im Management des Hundes unterstützen kann. Der Hund ist noch nicht an den Maulkorb gewöhnt. Da bisher keine Agressionsproblematik sichtbar wurde, stimmt der Therapeut einer Behandlung ohne Maulkorb in Anwesenheit der Trainerin zu.

Nach einer kurzen Kennenlernphase lässt sich der Hund gut anfassen und behandeln Zusammen mit der Trainerin wird entschieden, dem Hund immer wieder Pausen zu geben und vor allem Freiraum zu geben, um sich zurückziehen zu können. Bei der Behandlung fällt dem Therapeuten auf, dass der Hund sicher tierärztlich genauer untersucht werden müsste und teilt dies den anwesenden Personen mit (Dolenz). Die Behandlung geht dem Ende zu, die Besitzerin entfernt sich mit dem Hund an der Leine und steht zusammen mit der Hundetrainerin einige Meter entfernt. Als der Therapeut ebenfalls vom Boden aufsteht, greift der Hund den Therapeuten unvermittelt an, ein Biss wird glücklicherweise vermieden, da der Hund an der Leine ist.

Lerneffekt:

Sich nicht durch Anwesenheit von anderen Fachpersonen in Sicherheit wähnen und ablenken lassen. Immer während der gesamten Therapiezeit aufmerksam bleiben, v.a. auch am Ende der Behandlung. Vorsicht bei unsicheren Hunden bei der Behandlung am Boden, v.a. beim Aufstehen, das der Hund als Bedrohung auffassen kann.

Organisation:

Die Tierphysiotherapeutin arbeitet zum ersten Mal in einer grossen Tierklinik. Sie soll eine stationäre Katze mit Parese an der Hinterhand nach Unfall behandeln. Auf der Katzenstation ist extrem viel Betrieb und es gibt zurzeit keinen Platz, die Katze vor Ort zu behandeln. Die am Limit laufenden TPA's raten, die Katze hoch in die Physiotherapie mitzunehmen für die Behandlung. Auf die Frage, wie die Katze transportiert werden soll, meint eine der Angestellten, sie könne einfach auf den Arm genommen werden, die sei eine Liebe und könne ja durch ihre Verletzung eh nicht weglaufen. Auf dem Weg zum Therapieraum läuft die Tierphysiotherapeutin der behandelnden Oberärztin in die Arme und kassiert einen Vortrag über sicheren Transport von Tieren in einer Klinik (auch wenn das Tier noch nicht mobil war, der Weg vorbei am Haupteingang und Warteraum mit vielen Hunden war einfach gefährlich mit einem ungesicherten, der Klinik anvertrauten Tier).

Lerneffekt:

An neuen Arbeitsstellen die Gepflogenheiten und Sicherheitsstandards immer erfragen. Sich nicht durch gestresstes Personal abwimmeln und irritieren lassen. Katzen sind auch innerhalb der Klinik aus Sicherheitsgründen immer in der Transportboxe zu transportieren.

Social Media

Präsenz des SVTPT auf den diversen Plattformen

Der SVTPT ist bestrebt seine Präsenz auf Social Media zu verbessern und zu erhöhen. Des Weiteren haben wir einen Whatsapp Infokanal erstellt, auf welchem ebenfalls die Beiträge publiziert werden.

Wir halten nach wie vor an unserem erarbeiteten Konzept fest. Dies beinhaltet, dass wir versuchen jede Woche einen Fach- und Verband – Beitrag zu posten. Jeweils Dienstag Verbandsinterna und am Freitag einen Fachbeitrag.
Unser Ziel ist es weiterhin die Sammlung mit Fach - Content zu erweitern, damit wir sicher den Beitrag für Freitag vorgängig zur Verfügung haben, ohne jede Woche unter Druck etwas zu generieren. Selbstverständlich werden wir aktuelle Dinge vorziehen und einfügen.

Gesucht:
Interessante kurze Fallbeispiele mit Bildern oder sonstige interessante Beiträge oder auch Links zu interessanten Artikeln.

Eingabe:
Bitte sendet solche Beiträge an Isabelle Gysi gf@svtpt.ch, unsere Geschäftsführerin, die sich um das Posten kümmert.

Bitte:
Es wäre begrüssenswert und hilfreich für eine gesteigerte Präsenz, wenn alle Mitglieder, die in diesen Medien unterwegs sind, der SVTPT Seite jeweils folgen würden und die Beiträge teilen, sowie kommentieren

Untenstehend die verlinkten Buttons zu Facebook, LinkedIn und Instagram. Ebenfalls findet ihr den Link zum Whatsapp Kanal.

https://chat.whatsapp.com/EMxDiU1WtMGApW8Htko5TI

Bericht der Prüfungskommission PK

PK-Kommission:
Suzanne Burtscher, Kathrin Herzog, Saphira Lustenberger, Brigitte Stebler, Sabrina Studer

Die PK-Kommission besteht seit der Generalversammlung 2024 aus: Suzanne Burtscher, Kathrin Herzog, Brigitte Stebler, Sabrina Studer, Saphira Lustenberger (neu)

Isabelle Widmer hat die PK aus Zeitgründen verlassen.
Brigitte Stebler und Suzanne Burtscher amten als Co-Präsidentinnen.

Die HFP 2024 wurde erfolgreich durchgeführt.

An der HFP 24 nahmen insgesamt 18 Kandidierende teil, 17 neue und 1 Repetent.

Das stellte die Organisation vor Herausforderungen. Einerseits mussten genug Expertenteams gebildet werden, genug Räumlichkeiten zur Verfügung stehen und natürlich ein guter Zeitplan ausgeklügelt werden. Nicht zum vergessen die grosse Anzahl an Tieren und ihre Besitzer. Lea Knaus hat da grossartiges geleistet. 18 Pferde und 18 Hunde inkl. Besitzer und dazu noch 8 Pferde und 2 Hunde für die MLD-Prüfung.

Glücklicherweise konnten die praktischen Prüfungen erneut am Tierspital Zürich durchgeführt werden. Angesichts der hohen Anzahl an Kandidaten und Prüfungsteams wäre es äusserst schwierig, einen alternativen Austragungsort zu finden.

Die neuen Erkenntnisse aus den letzten Prüfungen haben wir in die Vorbereitung und Ausführung der HFP 2024 einfliessen lassen. So wurde die MLD-Prüfung vorverlegt, damit die Punktezahl in die praktische Prüfung einfliessen kann. Es werden neu max. 5 Punkte dafür vergeben, die in der praktischen Prüfung mitzählen.

Insbesondere die Schulung der Experten war von großer Bedeutung. Wir haben diesem Bereich viel Aufmerksamkeit gewidmet und neue Ideen umgesetzt, um die Experten bestmöglich vorzubereiten. Das Ziel ist, dass die Bewertung der Experten unter Berücksichtigung einheitlicher Kriterien erfolgt.

An folgenden Terminen haben Expertenschulungen stattgefunden

02.10.23 – *Fit mit Anatomie*: Interaktiver Online-Workshop für alle Experten. Ziel: Auffrischung der Anatomie. Der interaktive Ablauf fand großen Anklang, und es wurde einstimmig beschlossen, weitere einstündige Weiterbildungen durchzuführen. Diese erfolgten an 20.11.23, 29.01.24, 12.02.24 und am 11.03.24

08.04.24 – *DA Beurteilung und Notation*: Online-Schulung für DA-Experten mit Frau Sonja Schneiderbauer (Didaktik-Fachfrau). Ziel: Vereinheitlichung der Beurteilung und Festlegung der Bewertungsmaßstäbe.

29.04.24 – *Fachgespräch/Notation*: Online-Schulung für **alle** Experten mit Frau Sonja Schneiderbauer (Didaktik-Fachfrau). Ziel:

- Erarbeitung zielführender Fragen für Fachgespräche
- Überprüfung relevanter Kompetenzen
- Übung im Führen von Fachgesprächen inklusive Theorie und Praxistipps
- Präzise Ausführung der Notation: Bedeutung und Interpretation spezifischer Begriffe

31.08.24 – *Praktische Prüfung*: Individuelle Beurteilung eines Fallbeispiels (Hund und Pferd) und anschließende gemeinsame Diskussion online.

12.09.24 – *Allgemeine Schulung*

Die Expertenschulungen wurden sehr geschätzt und als grosse Unterstützung und wertvolle Auffrischung bezeichnet.
Im nächsten Prüfungszyklus werden wir wieder ähnlich vorgehen und auch auf die Bedürfnisse der Experten eingehen.

Die Prüfungen fanden an folgenden Daten statt:

- Schriftliche Prüfung: Fr 27.09.24
- Praktische Prüfungen: So 29.09.24, Sa/So 05./06.10.24
- MDL: Sa/So 28./29.09.24
- DA: Sa/So 26./27.10.24

Die Notensitzung wurde am **30.10.24** online abgehalten.

14 Kandidierende haben die Prüfung bestanden. Dabei war auch der Repetent.

4 Kandidierende haben die Prüfung oder Teile davon nicht bestanden.

Sie erhalten die Möglichkeit, diese nachzuholen. Sämtliche Prüfungsteile ausser den praktischen Prüfungen können im August 2025 erneut abgelegt werden. Die praktischen Prüfungen in den Bereichen Kleintier und Pferd können erst im Rahmen der HFP 2026 absolviert werden. Leider macht nur 1 Kandidat vom Prüfugstermin im August Gebrauch.

Die Diplomfeier am **29.11.24** fand wieder im Restaurant Frieden in Niederhasli statt. Eingeladen wurden nebst den Kandidierenden auch Experten und Dozierende.
Sehr stimmungsvoll wurde man bei klirrender Kälte draussen am Feuer mit Glühwein empfangen. Nach der Diplomübergabe an der Wärme wurde nochmals draussen mit Sekt und Häppchen angestossen. Ein feines Essen mit guten Gesprächen rundete die Feier perfekt ab.

Die Daten für die HFP 2026 stehen bereits fest:

- Schriftliche Prüfung: Fr 25.09.26
- Praktische Prüfungen: Sa/So 26./27.09.26 und Sa/So 03./04.10.26
- MDL: Sa/So 27./26.09.26
- DA: Sa/So 24./25.10.26

Juni 25, Suzanne Burtscher, PK

Zusatzausbildung 2024/26

Im April 2024 war der Start für die momentan laufende Zusatzausbildung, welche sich nun bereits im zweiten Jahr fortsetzt. Die reine Frauengruppe besteht aus 6 Tierärztinnen, 13 Physiotherapeutinnen und einer Biologin, welche sur Dossier aufgenommen wurde. Eine ursprünglich angemeldete Teilnehmerin konnte seit Beginn aus privaten Gründen leider nicht teilnehmen. Leider konnte der Platz eine Woche vor Beginn der Ausbildung nicht besetzt werden trotz Warteliste.

Um den 19 Teilnehmerinnen optimale Unterstützung bei den praktischen Anwendungen zu gewährleisten, wurde das Assistententeam 2024 vergrössert. Vielen Dank an Julie Ernst, Susanne Haag, Ursi Heggli, Joana Locher für euren Einsatz!

Die Ausbildungsstruktur wurde auch für diese ZA beibehalten. Eine selbständige Vorbereitung mittels stetig überarbeiteter MP4 - Dateien ermöglicht ein Arbeiten an höheren Lernzielen vor Ort. So wird nun Wissen verknüpft, transferiert und angewendet. Zusätzlich gibt es Zeit für Gruppenarbeiten und Diskussionen.

Im April dieses Jahres ging bedauerlicherweise eine grosse, prägende Ära zu Ende. Mit grosser Dankbarkeit für unglaublich lehrreiche Tage fanden die letzten Anatomietage mit Professor H. Geyer und Dr. M. Räber statt. Es bleibt dem gesamten Lehrteam nur noch, sich auch auf diesem Weg von Herzen für das dermassen grosse Engagement und enorme Wissen zu bedanken, von welchem wir viele Jahre so sehr profitiert haben. Alle diese Frischpräparate, säuberlich extra für uns präpariert und vorbereitet, waren extrem lehrreich. Eine Ära geht zu Ende, aber wir schauen zuversichtlich in die Zukunft, dass eine weitere Kooperation mit der Anatomie des Tierspital Zürichs möglich sein wird….

In den kommenden Monaten werden noch physiospezifische Themen, Pathologien diverser Fachrichtungen und deren Behandlungsmöglichkeiten erarbeitet. Auch neue Erkenntnisse aus der aktuellen Forschung fliessen stets mit ein. Zusätzlich stehen noch einige Tage zum Modul 5 und 6 an. Modul 5 beinhaltet Sattel / Geschirre / Longieren / Reiten und Modul 6 alles, was zur selbständigen Berufsausübung dazugehört. Diese Fachgebiete, die die HFP von einer Berufsprüfung abheben.

Auch die Craniosacraltherapie und die manuelle Lymphdrainage werden noch behandelt werden, sowie die apparativen Massnahmen.

An dieser Stelle- wie in jedem Artikel- möchte ich gerne alle Aktivmitglieder dazu aufrufen, einzelnen Tagen der ZA beizuwohnen! Das Programm ist auf der Homepage ersichtlich. (Ausbildung/ Lehrgang/ Module / Kursdaten 2024/2026)

Abtwil, im Juni 25, Lea Knaus

EduQua Zertifizierung

Nach der erfolgreichen Rezertifizierung am 24. Mai 2024 fand dieses Jahr das erste Aufrechtserhaltungsaudit am 06. Juni dieses Jahres statt. In einer 3-stündigen Videokonferenzfand wurden die vorab eingegebenen Dokumente, die der Auditor gesichtet hat, besprochen. Der Auditor stellte konkrete Fragen auf Grund der Dokumente und so wurde pro aktiv gezielte Themen angesehen und diskutiert. Immer wieder von Neuem eine sehr angenehme und wertvolle Zusammenarbeit mit ebensolchen Tipps. Keineswegs nur ein Prüfen, sondern auch ein Weiterentwickeln unseres Qualitätsmanagement und somit unserer Qualitätssicherung.

Grundsätzlich sind wir für den Auditor sehr zufriedenstellend unterwegs und es gibt vor allem die jährlichen Dokumente wie die Selbstevaluation, das QM-Handbuch und die SWOT - Analyse zu überarbeiten. Neue Dokumente braucht es keine, es gibt nur kleine Details zu ergänzen. Dieses jährliche Überprüfen ist sehr positiv, da dadurch ein leichter Druck da ist, alles sauber abzulegen und immer wieder zu überdenken und weiterzuentwickeln. Ich bin sehr froh, haben wir vor einiger Zeit das Projekt in die Hand genommen und ein griffiges System entwickelt. Es hat sich auf alle Fälle gelohnt.

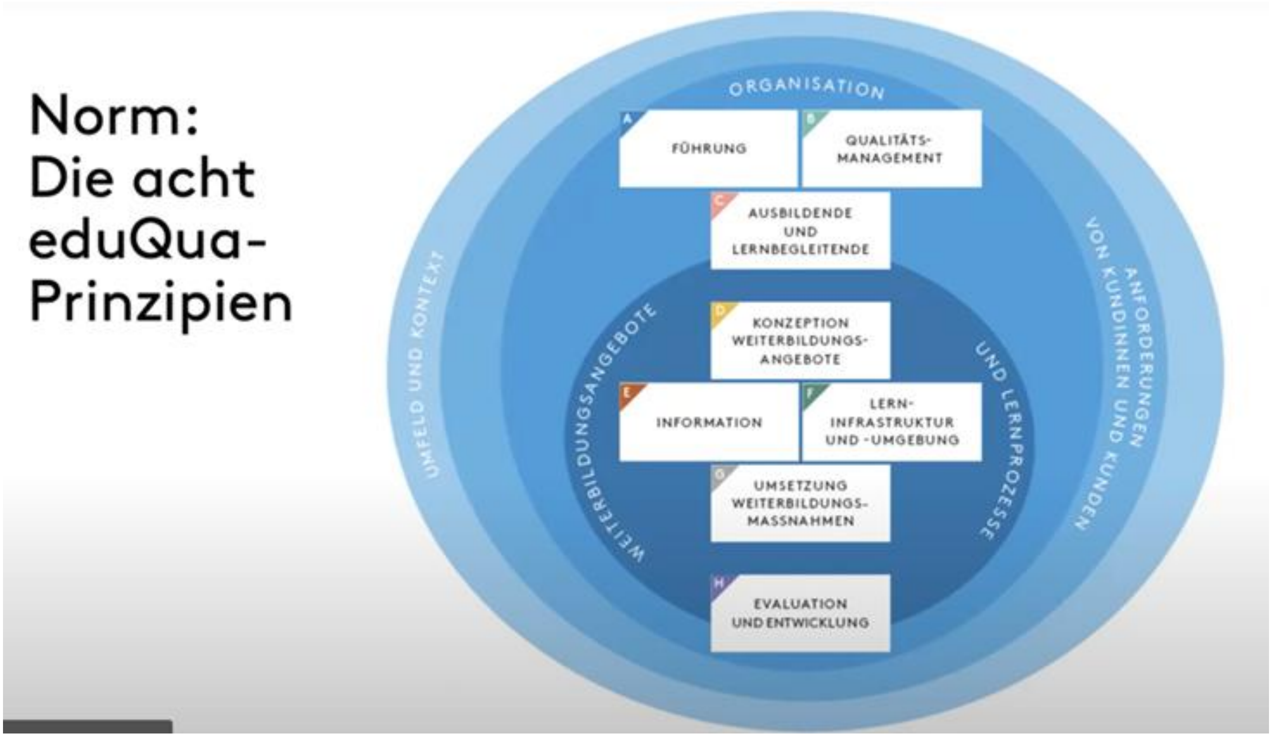
In Juni 2026 wird dann das zweite Aufrechtserhaltungsaudit stattfinden. Neu wird in diesem AA eine Teilnehmerin für ein Interview aus der ZA 24-26 zugeschaltet, Dauer ca. 20 Minuten.

An dieser Stelle ein herzliches Dankeschön an Alle, speziell an das Lehrteam, das immer kooperativ und aktiv alle Qualitätssicherungen mitträgt.

Das Reflektieren der eigenen Arbeit ist immer sehr nützlich und Prozesse können verbessert und in den Arbeitsablauf eingliedert werden. Das ist nicht immer ganz einfach, da man dadurch auch eine gewisse Komfortzone verlassen muss. Im Lehrteam funktioniert das sehr gut. Jeder arbeitet daran und so verbessert sich die Qualität zusehends.

Danke Lehrteam!

Hier nochmals den Überblick über das neue System der Zertifizierung:



Die Organisation steht in den 2 Kreisen «Umfeld und Kontext» und dem Kreis «Anforderungen von Kundinnen und Kunden».

Qualitätsregelkreis:

2. Regelkreis: Weiterbil-

Einfluss von TENS auf die postoperative
TENS-Behandlung durch Besitzer in der Frühphase – sinnvoll oder nicht?

dungsangebote und Lernprozesse integriert:

Angebote, Information, Infrastruktur (Lernumgebung), Planung - Umsetzung, Evaluation / Entwicklung.

SVTPT: SWOT-Analyse
erstellt März 2024, überarbeitet/Verifiziert Mai 2025

Innerwelt-Analyse (innere Faktoren)	
Stärken (Strenghts): - Abschluss auf Tertiär B Niveau HFP - Fachspezifische Vorbildung mit Berufserfahrung - Intensive, umfassende Ausbildung - Hochqualifizierte und erfahrene Referierende - Vom Bund subventionierte und akkreditierte Ausbildung - Einzige Ausbildung, die konkret und umfassend auf den Abschluss Tierphysiotherapeut mit eidg. Diplom vorbereitet - EduQua zertifiziert - Andragogische und didaktische Begleitung der Referierenden - Stetige Weiterbildung der Referierenden - Hund und Pferd in einer Ausbildung, dadurch fördern der Transferkompetenz - Q-Sicherung durch obligatorische Weiterbildung - Coaching nach Diplom mittels Q-Zirkel - Geschult in Clinical reasoning und Flagkonzept dadurch optimal vorbereitet für den Direktzugang - Grunderfahrung im Berufsleben durch Primärberuf - Regelmässige Präsenz in Social Media - FA Physiotherapie bei der Camvet / GST - Sur Dossier Zugang - Interdisziplinäre Ausbildungslehrgang - Herausforderung der korrekten "Flughöhe" durch die verschiedenen Möglichkeiten des Zugangs (Humanphysioth. / TA / sur Dossier - Verbindung fachlicher Ausbildung und selbstständiger Berufsführung (HFP als Abschluss) ist optimale Voraussetzung für erfolgreiche selbstständige Erwerbstätigkeit	**Schwächen (Weakness):** - Lange anspruchsvolle Ausbildung - Zeit- und finanziell aufwändig - Niederprozentiges Arbeiten, da oft 2. Standbein - Ausbildung immer in beiden Tierarten - HFP in beiden Tierarten - Umfassende Abschlussprüfung mit zeitintensiver Vorbereitung - Ausbildung und Unterlagen nur auf Deutsch - Hohe Ausgaben für Referierende im Modul 6 (selbstständige Berufsführung)

Chancen (Opportunities):	**Threads (Gefahren):**
- 2. Standbein erarbeiten (Tarifdiskussion Physiotherapie) - Notfalldienst umgehen - Mensch und Tier gemeinsam behandeln - FA Physiotherapie der Camvet: Ausbildungsniveau festgelegt durch Voraussetzung eidg. Diplom für FA - Bekanntheitsgrad steigt durch FA bei den Tierärzten - Tierbesitzer fragen vermehrt nach Fachkompetenz bei tierärztlichen Tätigkeiten und so steigt der Stellenwert der Physiotherapie - Grössere Kliniken beschäftigen vermehrt spezialisierte Fachkräfte, da Nachfrage seitens Besitzer da ist - Interessierte Personen durch "sur Dossier" Verfahren aufnehmen und dadurch topmotivierte Teilnehmende generieren - Offenheit der Studierenden für Online Vorbereitung, hybrid Durchführung einzelner Tage - Hybride Durchführung der Kurstage - Viel Zeit für praktische Arbeit und Vernetzung - Kürzere Präsenzzeiten - "Lernen voneinander" innerhalb der Ausbildung - Medienpräsenz mit Fachartikel - Hund und Pferd sind nicht nur Haustiere, sondern auch im Sport im Einsatz, dadurch vermehrtes Potential für Fachleute mit Fachwissen	- Hohe Arbeitslast der einzelnen Personen - Niedrigprozentiges Arbeiten und dadurch Qualitätseinbusse durch zu wenig Erfahrungsaufbau - FA Physiotherapie: Tierärzte haben höheren Stundenansatz, dadurch ev.Tarif Erhöhung - Kliniken versuchen Preis zu drücken durch weniger hochqualifiziertes Personal oder durch Einschränkung der Behandlungszeit - Anspruchsvolle Kundschaft, die sofort Erfolge sehen will und somit höheres Frustrationspotential, bei nicht sofortigen Erfüllen der Erwartungen. Überforderung der Fachpersonen - Allfälliger Strategiewechsel bei Bundessubventionierung - Weniger finanzielle Mittel für zusätzliche Ausbildungen durch Rezession - Deutschschweiz lastig - Weniger hoch qualifizierte Konkurrenz mit mehr PR Präsenz - Freiwilligenarbeit sinkt - Zu wenig unterstützende Mitglieder
Umweltanalyse (externe Faktoren)	

Massnahmen (Strategien):

S/O Strategie	**Mit welchen Stärken nutzen wir welche Chancen?** **Was sind die Massnahmen aus dieser Kombination?** Mit der hochqualifizierten Ausbildung helfen wir den Auszubildenden zu einem fundierten Wissen und zur Kernkompetenz der physiotherapeutischen Behandlung von Tieren. Und erarbeiten die Transferkompetenz. Handlungsorientiert und vernetzt arbeiten lernen.
S/T Strategie	**Mit welchen Stärken begegnen wir welchen Gefahren?** **Welche Stärken können eingesetzt werden, um Gefahren zu eliminieren?** **Was sind die Massnahmen aus dieser Kombination?** Junge Leute nachziehen, um Arbeitslast zu verteilen Frischdiplomierte animieren am Anfang des Berufslebens hochprozentig zu arbeiten, um Erfahrung zu sammeln und dann reduzieren. Begleitung / Coaching nach dem Diplom Tarifanpassung evaluieren Strategischer Berufsverband, der sich für seine Mitglieder einsetzt und beratend zur Seite steht
W/O Strategie	**Wie können aus Schwächen Chancen entstehen?** **Was sind die Massnahmen aus dieser Kombination?** Vorteile aus der Kombination der Tierarten herausstreichen. Vernetzung und dadurch Weiterentwicklung mit erhöhtem Potential aufzeigen. Beschäftigungsgrad erhöhen durch Einsatz bei beiden Tierarten Sur Dossier Aufnahme propagieren
W/T Strategie	**Wo befinden sich unsere Schwächen und wie schützen wir uns vor Risiken?** **Was sind die Massnahmen aus dieser Kombination?** Zeitintensive und teure Ausbildung durch hohe Qualität aufzeigen. Wichtigkeit der praktischen Arbeit aufzeigen, da zwingend für eine hohe Qualität und optimale Vorbereitung für den Beruf. Q-Sicherung Qualitätssicherung aufzeigen Ausbildung zweisprachig D-F? Ev Unterlagen übersetzen? Ev Englisch als 2. Sprache? Dadurch auch vermehrte internationale Vernetzung möglich und Q-Steigerung durch Austausch PR für den Beruf hochhalten. Kunden auf unterschiedliche Qualität sensibilisieren Zusammenarbeit mit Tierärzten und Kliniken vermehrt aufbauen

Vorschau auf die restlichen Weiterbildungen 2025 und Ausblick auf 2026

September 2025

Weiterbildungen

27. – 28. September 2025

KVD Halle, Niederhaslistrasse 13, Dielsdorf

Neuromotor control in equine rehabilitation

Theory: Functional anatomy and biomechanics: evidence-based concepts of mechanoreception, nociception and joint mobilization/range of motion (ROM) in function/ dysfunction of the equine spinal column; Neuromotor control: evidence-based concepts of motor control in dynamic functional stability: what …

Details | Anmeldung

Oktober 2025

Weiterbildungen

13. Oktober 2025 um 19:30 – 21:15

Teams Video-Konferenz

Abendveranstaltung - Konservative Orthopädie, Verbände und Schlingen

Wann muss der Chirurg nicht schneiden; Gestaltung einer konservativen Therapie; korrektes Anlegen von Verbänden und Schlingen

Details | Anmeldung

November 2025

GV / Tagung

19. November 2025 um 19:30 – 21:30

online per Teams-Videokonferenz

Generalversammlung SVTPT 2025

Generalversammlung 2025

Details | Anmeldung

Weiterbildungen

28. November 2025 um 16:00 – 20:00

KVD Dielsdorf oder online

Bildgebende Verfahren kennen und Bilder lesen lernen

Übersicht über die verschiedenen Möglichkeiten der bildgebenden Verfahren; Wann und warum wird welches bildgebende Verfahren eingesetzt; Vor- und Nachteile der Verfahren; Wie lese ich die Bilder? Gibt es eine systematische Herangehensweise?; Lagerungen für bestimmte Aufnahmen und deren …

Details | Anmeldung

Dezember 2025

Weiterbildungen

1. Dezember 2025 um 19:30 – 21:15

Teams Video-Konferenz

Abendveranstaltung - Vorstellung und Diskussion von 3 Diplomarbeiten "Pferd"

Evaluation von Zusammenhängen zwischen Zahnstellung beim Pferd und seiner Diagonalität Das Sidewinder Syndrom des Pferdes: Ist die physiotherapeutische Behandlung eine geeignete Therapie bei Pferden mit Sidewinder Syndrom? EVVM und ECRM: Welche Auswirkungen haben ECVM und ECRM auf die …

Details | Anmeldung

Januar 2026

Weiterbildungen

17. Januar 2026 um 08:45 – 18:00

Teams Video-Konferenz

Online Congress

The Swiss Association of Animal Physiotherapy will organize the 4th online congress in January 2026. Accreditation by the Society of Swiss Veterianarians (GST): 4 hours (half day) 8 hours (full day)

Details | Anmeldung

Februar 2026

Weiterbildungen

2. Februar 2026 um 19:30 – 21:15

Teams Video-Konferenz

Abendveranstaltung - Vorstellung und Diskussion von 3 Diplomarbeiten "Kleintier"

Optimales Warm-up und Cool-down für Agility-Hunde zur Prävention von Sportverletzungen: Wie gestaltet sich das optimale Warm-up und Cool-down für einen Agility-Hund unter Berücksichtigung der biomechanischen Abläufe? Einfluss von TENS auf die postoperative Phase bei Hunden nach …

Details | Anmeldung

Juni 2026

Weiterbildungen

5. – 7. Juni 2026

Horse Park Zürich-Dielsdorf AG, Neeracherstrasse 20, CH-8157 Dielsdorf

oder per Teams-Video-Konferenz

Hybrid-Kongress

The Swiss Association of Animal Physiotherapy is organizing a three days hybrid congress in June 2026. Every day will be split in half day presentations (one stream small animals and one stream horses) and half day workshops. A topic of general interest will finish the day. Please check the …

Details | Anmeldung

Weiterbildungen

6. Juni 2026 um 18:30 – 21:15

Horse Park Zürich-Dielsdorf AG

Horses Inside Out: Abendshow mit Gillian Higgins (GB)

Gillian Higgins wird live eine einmalige Darbietung präsentieren: an zwei Pferden, die von ihr in einer minutiösen Genauigkeit bemalt wurden auf einer Seite mit der Muskulatur und der anderen Seite mit dem Skelett, zeigt sie die Biomechanik in der Bewegung an der Longe und unter dem Sattel, …

Details | Anmeldung

Oktober 2026

Weiterbildungen

26. Oktober 2026 um 19:30 – 21:30

Teams Video-Konferenz

Abendveranstaltung - Innere Medizin - Erkrankungen und ihren Einfluss auf den Bewegungsapparat beim Kleintier

Details folgen

Details | Anmeldung

Q – Zirkel 2025

September 2025

Q-Zirkel

4. September 2025 um 19:30 – 21:00

Teams-Videokonferenz

Tierphysiotherapie Gross- / Kleintiere

Teilnehmer stellen Fallbeispiele vor, die miteinander fachlich analysiert und diskutiert werden. Interaktiver Austausch / Diskussion von fachlichen Neuigkeiten.

Details | Anmeldung

November 2025

Q-Zirkel

6. November 2025 um 19:30 – 21:00

Teams-Videokonferenz

Tierphysiotherapie Gross- / Kleintiere

Teilnehmer stellen Fallbeispiele vor, die miteinander fachlich analysiert und diskutiert werden. Interaktiver Austausch / Diskussion von fachlichen Neuigkeiten.

Details | Anmeldung

Bachs, im Juli 2025, Brigitte Stebler i.V. Nadine Caldelari

MP4 Dateien aus der Zusatzausbildung als Weiterbildung

Aktivmitglieder können zu untenstehenden Konditionen einzelne Module und Modulteile zur eigenen Weiterbildung kaufen. Die Unterlagen bestehen aus MP4 Dateien, PDF der dazugehörigen Folien und das Skript. Zusätzlich werden zur Lernkontrolle und Reflexion Arbeitsblätter abgegeben. Genauer Inhalt der einzelnen Module finden sie unter Module

- Modul 2: Anatomie: 11 Std = CHF 200.-
- Modul 2: Biomechanik: 12 Std = CHF 200.- (9.75 Std. nur Hund)
- Modul 3: Neurologie: 11 Std = CHF 200.-
- Modul 4: Befundaufnahme; passives Bewegen; Behandlungstechniken (passiv u. aktiv) Physiotherapie relevante Pathologie:
  Gesamtpaket = 500.- (43.75 Std. - Hund 23 Std. - Pferd 35 Std)
- Modul 5: Sattel / Geschirre Pferd und Hund / Reiten aus biomechanischer Sicht / Longieren Pferd und Hund 4.75 Std = CHF 80.-
- Modul 6: Finanzen: 1.75 Std = CHF 30.-
- Modul 6: Q-Sicherung = 2 Std = CHF 30.-

Für die Anrechnung als obligatorische Weiterbildung gilt folgende Regelung:

- 12 Std = 1 Tag (zählt zur Hälfte)
- 1 WB Tag / Jahr bzw. 2 / WB Zyklus wird angerechnet
- Arbeitsblatt / Modul zur Kontrolle muss ausgefüllt und eingegeben werden an gf@svtpt.ch zur Q-Sicherung. Danach können die Stunden als WB angerechnet werden.

Weiter gilt auch das Angebot "Teilnahme vor Ort". Dabei werden die MP4-Dateien, PDF und Skripte als Vorbereitung abgegeben. Diese Möglichkeit kann auch als WB angerechnet werden. 1 Tag Zusatzausbildung inkl. Studium der vorbereitenden Dateien wird als 1 Tag WB angerechnet. Diese Möglichkeit lohnt sich für Aktivmitglieder, die an einem speziellen Thema interessiert sind und auch die praktische Arbeit mitmachen möchten.

Die genauen Themen sind ersichtlich unter Kursdaten

Anmeldung direkt an brigitte.stebler@svtpt.ch

Der Preis beträgt 100.- / Tag inkl. Unterlagen

Online Kongress 17. Januar 2026

Dank dem regen Interesse beim online Kongress von den letzten Jahren, haben wir beschlossen wieder einen Tag zu organisieren. Internationaler Austausch ist zielführend und online klappt das ja ganz gut.

Wir werden das Tagesprogramm auf 3 Referate Grosstier und 3 Referate Kleintier beschränken wie dieses Jahr. Zwischen den Referaten wird es immer eine kurze Pause geben, um die Beine zu vertreten und für uns, um die Technik umzuschalten von einem Referenten zum anderen. Alles in allem etwas entschleunigt gegenüber den Vorjahren. Das hat sich sehr gut bewährt.

Vielleicht ist auch jemand unter euch, der gerne etwas dazu beiträgt. Gerne erwarten wir eure Rückmeldung an Isabelle Gysi, gf@svtpt.ch.

Medien

Folgende Artikel über Tierphysiotherapie oder tierphysiotherapeutisch relevante Themen sind im der Zeitspanne August 24 und Juli 25 in unterschiedlichen Medien erschienen. Alle Artikel sind auf der Webseite zum Download aufgeschaltet.

Artikel über die Tierphysiotherapie in diversen Fachmagazinen

Kavallo 06 / 2025

Altersturnen für Pferde

Hunde 04 / 2025

Mens sana in corpore sano

anima.li

IL CAVALLO DA DRESSAGE - Il ballerina professionista

Hunde 01 / 2025

Der Hund in Bewegung

Kavallo 05 / 2025

Slow - Feeding - Systeme und der Bewegungsapparat

Kavallo 04 / 2025

Decken und Co. aus physiotherapeutischer Sicht

SAT / ASMV 04 /2025

Zusatzausbildung Tierphysiotherapeutin / Tierphysiotherapeut mit eidg. Diplom

anima.li

Il cavallo da salto – Fusione di potenza, velocità ed eleganza

Kavallo 01 - 02 / 2025

Boxenruhe - Übungen fürs Nervensystem

Kavallo 12 / 2024

Boxenruhe - „Use it or lose it“

Hunde 07 /2024

PNF für Helden auf vier Pfoten

Kavallo 11 / 2024

Core - Stabilisation beim Pferd

Kavallo 10 /2024

Interaktion Pferd - Boden: biomechanische Analyse

Kavallo 09 /2024

Boxenruhe - wichtigste Übungen für zu Hause

Hunde 05 / 2024

Einsatz des Unterwasserlaufbands

Kavallo 08 /2024

Physiotherapie bei Zahnproblemen

Alltagsübungen

SVTPT
FSPA
FSFA
FSFB

SCHWEIZERISCHER VERBAND FÜR TIERPHYSIOTHERAPIE
FÉDÉRATION SUISSE DE PHYSIOTHÉRAPIE POUR ANIMAUX
FEDERAZIONE SVIZZERA DELLA FISIOTERAPIA PER ANIMALI
FEDERAZIUN SVIZRA DELLA FISIOTERAPIA PER BES-CHAS


Alltagsorientierte Ideen und Übungen

Rehabilitation und Prähabilitation

Unsere Broschüre zu den Alltagsübungen Kleintier ist nach intensiver Arbeit geboren.

Wir bieten euch diese Broschüre gedruckt zum Kauf an damit ihr sie an eure Kunden zu einem symbolischen Preis abgeben könnt. Es ist auch möglich das PDF zu erwerben und es elektronisch abzugeben. Bestellung direkt an info@svtpt.ch

Preise:

- 10 Exemplare (Mindestbestellmenge) Stück CHF 15.- = CHF 150.-
- 30 Exemplare Stück CHF 14.- = CHF 420.-
- 50 Exemplare Stück CHF 12.- = CHF 600.-
- PDF CHF 250.-

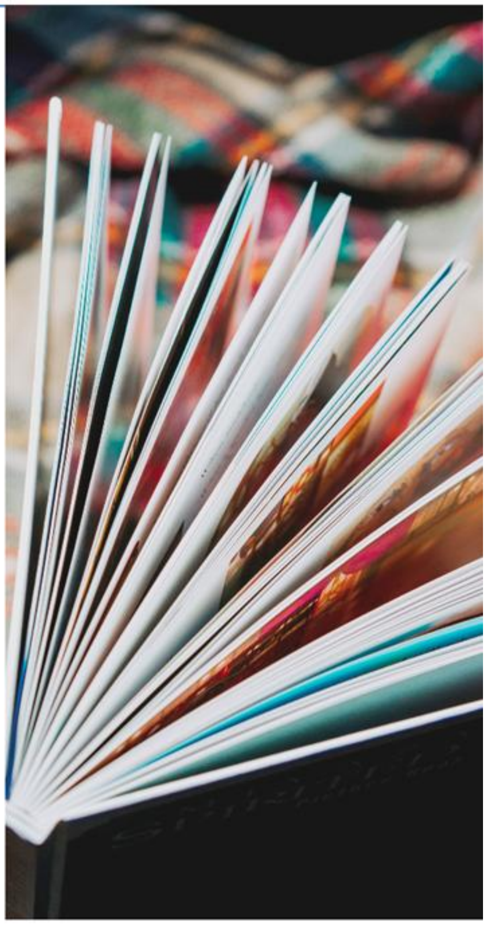
Die Übungen sind detailliert bildlich dargestellt und die Vor- und Nachteile beschrieben.

Folgende Übungen sind enthalten:

Übersicht

Rehabilitation
- bei Altersbeschwerden
- nach Krankheit oder Unfall

Prähabilitation
- für junge Hunde
- für gesunde Hunde



Beispiel des Aufbaus und Beschriebs einer Übung:

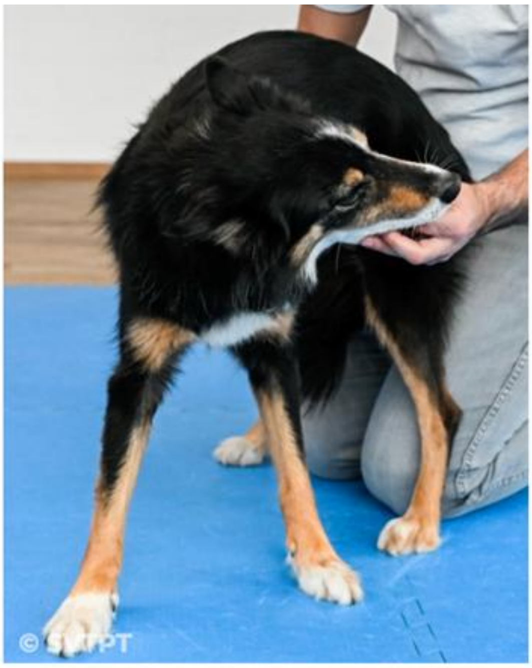
Leckerli Yoga

Mit Leckerli langsam zu Hüfte, Knie, Zehen, Hoch in die Luft, runter zum Boden führen

Im Sitz oder Stand

Effekt auf Beweglichkeit Rumpf und Wirbelsäule bzw. Muskulatur

Beobachte ob eine Seite steifer ist?



Hilfsmittel: Leckerli / Apfel / Rübli / «Deo Roller» / Leckmatte

- Sollen sich NICHT drehen

- Immer vor dem Essen: Gewohnheit einüben
- Kleine Leckerli wählen (Gewichtskontrolle) Leckmatte / Leckpaste
- 3 Wiederholungen je Übung

3

Und zuletzt noch ein paar allgemeine Tipps:

Informationen zum Thema «Gesundheit»

Gesundheit allgemein

- Halter/innen müssen aktiv involviert werden, nur so kann die Lebensqualität von jungen, älteren und rekonvaleszenten Hunden erhalten bleiben
- Hunde haben schlechte und gute Tage: Diese erkennen und respektieren
- Fundus an Übungen, die einfach und intuitiv in den Alltag integriert werden können
- Vermeiden von teuren Anschaffungen und Möglichkeiten in engen Platzverhältnissen
- Die 3 wichtigen Komponenten beüben: KRAFT / BEWEGLICHKEIT / AUSDAUER
- *Alle Übungen können auch mit jungen Hunden oder Hunden nach bestimmten Verletzungen in Absprache mit der Tierphysiotherapie durchgeführt werden*

Gesundheit im Alter

- Alte Hunde haben schlechte und gute Tage: Diese erkennen und respektieren
- Beobachten von körperlichen Veränderungen
- Verlangsamen von Alterserscheinungen
- Muskelabbau und Verlust von Mobilität verlangsamen
- Geistige und körperliche Mobilität fördern
- Pausen respektieren, trotzdem Kondition fordern und fördern

Beachte

- Überlastungen vermeiden!
- Achtsamkeit im Alltag und auf Spaziergängen auf Zeichen wie:
  - Unruhe
  - Vermeidungshaltungen
  - Form- und Gewichtsverlust
  - Schmerzen / Zittern bei Anstrengung
- Viel Bewegung – Wenig Belastung
- Verletzungen, auch Bagatellen, sind bei Senioren langwieriger und komplexer, wie bei jungen und fitten Hunden

20

Referenzen

1. Carrie Smith (Canada)

BScPT, CCRT, CAFCI, Cert. Sport Physio, Cert. Gunn IMS; Kemptville Canine Centre (Ottawa, ON, Canada)

- A 6-Week Senior Dog Wellness Programm

2. Hielm-Bjorkman HK, et al

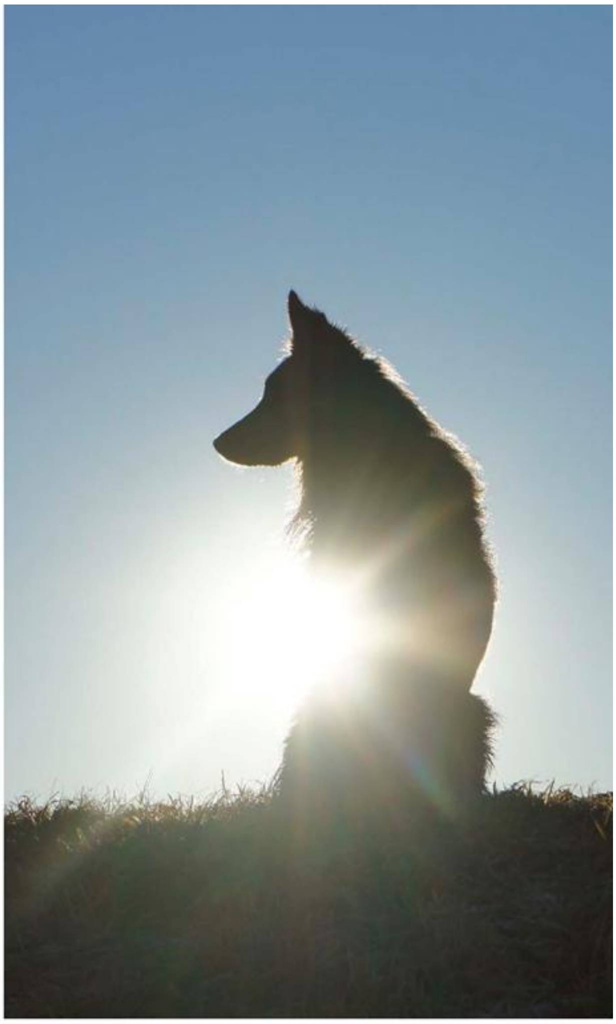
- Helsinki Chronic Pain Index

3. Realisation

- Dimitrios Manoglou, *www.tierphysio-dimi.ch*
- Brigitte Stebler
- Gruppe Qualitätszirkel, *www.svtpt.ch*

4. Bilder

- Katja Stuppia, *www.fotografie-stuppia.ch/*
- Katrin Staratzke
- Nicole Good
- Dimitrios Manoglou *mit den Models: Karli, Benji und Nöldi*



SVTPT
FSPA
FSFA
FSFB

Weitere Informationen und Kontakt zu Therapeut:innen unter:

SVTPT

Postfach
8162 Steinmaur

https://svtpt.ch
info@svtpt.ch

Finanzen sichern

Wie bereits im Vorwort erwähnt, sucht der SVTPT nach Geldquellen.

Warum?

Wir sind ein selbstständiger, offizieller Berufsverband, eine kleine Non Profit Organisation mit ca. 130 Mitglieder. Unser Verband ist EduQua zertifiziert und bürgt dadurch für Qualität. Diese soll weiterhin ein Markenzeichen von uns sein. Diese gesamten Prozesse sind sehr nützlich, brauchen aber Zeit, Know-how und Ressourcen. Externe Hilfe ist kostspielig, aber wichtig und auch nötig.

Ich führe diesen Verband seit 1998 mit viel Herzblut und Einsatz und wenig finanziellem Ertrag. Meine Präsidialzeit geht dem Ende entgegen und neue, junge und enthusiastische Leute müssen übernehmen. Wem kann ich so viel Arbeit für so wenig Geld zu muten? Für mich ist es etwas anderes, es ist mein Baby und dafür tue ich alles. Nachkommende Fachkräfte sollen die strategische Führung übernehmen und weiterführen. Das Operative kann gut von Aussenstehenden übernommen und getätigt werden. Isabelle Gysi, unsere Geschäftsführung, übernimmt immer mehr Aufgaben und sieht so immer mehr hinter die Kulisse, was sehr gewinnbringend ist. Externe Vergabe von Aufgaben heisst aber auch eine höhere finanzielle Belastung. Darum brauchen wir mehr verfügbares Geld für die Zukunft.

Es gibt verschiedene Möglichkeiten Geld zu generieren:

1. Sparen bei den Ausgaben
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Bachs im Juli 25, Brigitte Stebler

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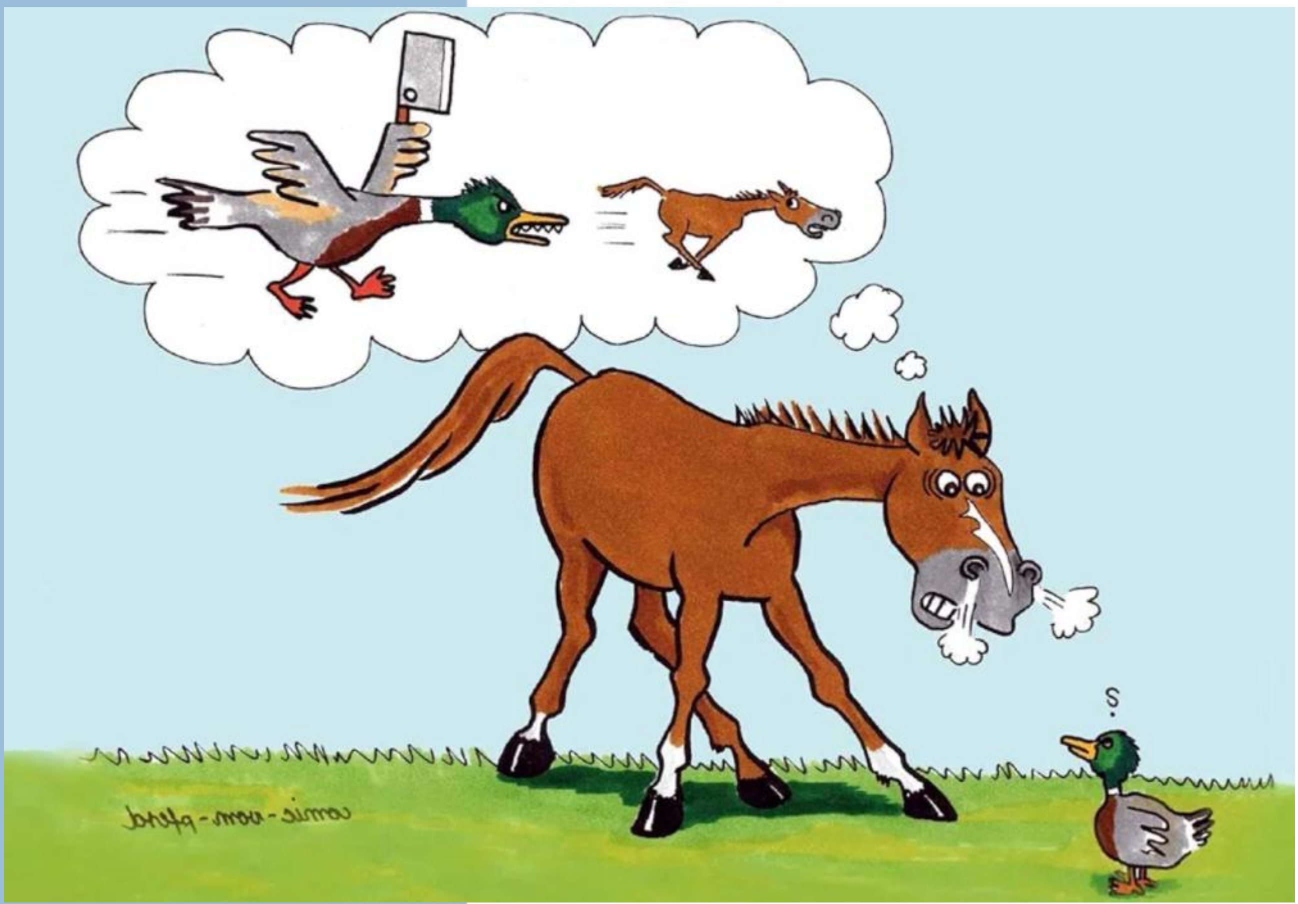

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Effects of different shoeing conditions on equine cervical and back kinematics during walking and trotting on a soft surface

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ABSTRACT

There is a paucity of scientific data on the effect of shoeing on equine neck and back kinematics during locomotion over commonly used sand training surfaces. A better appreciation of how alterations at hoof-ground interface influence equine upper body movements is relevant for improving horse's health and performance. Our objectives were to determine the effects of different shoeing conditions on equine neck and back kinematics at walk and trot in straight line over sand. Two-dimensional kinematic video analysis was performed under seven shoeing conditions: front feet shod with aluminum shoes and hind feet with steel racehorse shoes (REFSHOD), front aluminum shoe and hind feet unshod (FORESHOD), front feet unshod and hind steel race shoes (HINDSHOD), all four feet unshod (UNSHOD), front feet shod in combination with hind egg bar shoes (hEGGBAR), hind wide toe shoes (hTOE) and hind reverse shoes (hREVERSE). Data indicated that joint angles in the cervicothoracic junction were four times more likely to be significantly affected by the shoeing condition than in the back and sacrum. FORESHOD largely modifies the kinematics in comparison to REFSHOD or UNSHOD, with respectively a 6-11±1-2° (P<0.001) increased cervicothoracic extension at walk and trot, and a 3-4±1° (P<0.05) increased thoracolumbar flexion at trot. In comparison to REFSHOD, hEGGBAR, hTOE and hREVERSE induce a 5-7±1-2° (P<0.05) increased cervicothoracic extension at trot and walk respectively, and UNSHOD induced cervicothoracic flexion at trot (6±2°, P<0.05). In conclusion, shoeing conditions impact equine neck and back position, which should be considered during clinical examination, rehabilitation and training.

1. Introduction

In broad terms, the equine vertebral column may be characterized as a rigid structure [1]. However, more thorough investigations of the thoracolumbar and lumbosacral kinematics have started to reveal the nuances of equine spinal mobility [2-5]. For example, at trot, there is a 4° flexion-extension range of motion in the mid-thoracic, thoracolumbar and lumbosacral areas [6]. It is also noticeable that the variability in back range of movement between horses is four times larger than within an individual horse [6-10]. With advances in diagnostic imaging techniques over the last 25 years, lesions and pathophysiology of cervical and back areas can now be more readily understood.

Multiple factors have been identified to influence the movement of the equine back, and this is relevant for the treatment and rehabilitation of horses with back problems, in addition to the general wellbeing and performance of all horses. For example, back pain can reduce the range of motion at the 17th thoracic vertebra [11]. In contrast, the overall flexion-extension range of motion in the back may increase after the injection of lactic acid, mepivacaine or saline into the thoracolumbar multifidus muscle [10,12,13], with the load of a rider [14], and with induced fore- or hindlimb lameness [15,16]. Weighted boots, chiropractic manipulation and water depth in a treadmill can also influence

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thoracolumbar range of motion [10,17-19]. In addition, head and neck positions can also influence equine back movement [7]. Therefore, when riders induce hyperflexion of the neck, for example through “rollkur” in dressage, this is expected to have an impact on back movement, and may be a contributing factor to the welfare concerns raised by veterinarians and the Fédération Equestre Internationale (FEI) [7,18,20]. Nonetheless, in comparison to the thoracolumbar and lumbosacral area, neck kinematics have been less extensively studied. This requires further attention, given that osteoarthritis and instability of the lower neck affect nearly two-thirds of sport horses, with variable clinical significance [20-23]. In particular, one factor requiring further investigation in respect to both back and neck kinematics is the potential impact of shoeing.

The aim of this study was to quantify joint angles in the cervicothoracic, thoracolumbar and lumbosacral regions of horses trialing seven shoeing conditions at walk and trot on a soft surface. Previous work has identified that saddle horse aluminum shoes and/or steel racehorse shoes on sand have a greater influence on proximal than on distal joint angle [24], demonstrating that the upper body can be sensitive to changes at the hoof-ground interface. In addition, when compared to barefoot, shoeing can increase the amplitude of the thoracic dorsoventral displacement at trot in warmblood horses [25]. In association with the less animated gait observed in barefoot versus shod horses [25], we hypothesized that horses will have a lower neck position when walking and trotting in the barefoot condition compared to locomotion under different shoeing conditions. We also hypothesized that a combination of front feet shod and hind feet unshod would increase thoracolumbar flexion compared to a combined front and hind shod condition.

2. Materials and methods

2.1. Ethical approval

The experimental design was approved by the Direction Départementale de la Protection des Populations du Calvados (France). The agreement experimentation number for the Centre Hospitalier Vétérinaire Equin de LIVET (experimentation center) was A14214016. The agreement procedure was registered by the DDPP of Calvados (France) under the number R-45GRETA-F1-04.

2.2. Horses

A convenience sample of six horses (cross mixed saddle horses, three females and three geldings, aged 8–19 years old, body mass 430–720 kg, and height at withers 151–172 cm) were recruited for this study. The horses were usually kept unshod and regularly trimmed at 8-week intervals. All horses were clinically sound at the walk and trot in straight-line and they had no history of lameness in the six months prior to the study, as assessed by a veterinarian. All horses were housed in a paddock and were not in work for at least one year prior to the study. The training level and initial shoeing condition of the horses used in this experimental setup should be considered when interpreting the results, which could vary if the experimental setup were to be applied to regularly shod sporthorses.

2.3. Surface conditions

All measurements were performed on a sand surface in an outdoor arena (comprising 30 cm limestone, 10 cm draining sand with a 4 mm granulometry, and 12 cm of a superficial Martot’s sand), which is regularly watered and levelled. An examination area of 3 m by 12 m was set up with ground rails. The runway was maintained by raking between each trial.

2.4. Shoeing conditions

Seven shoeing conditions were compared (Fig. 1):

- Condition 1: reference shoeing condition (REFSHOD), to which all other shoeing conditions were compared. This comprised aluminum shoes (AC Concept product, with a mass of 240–260g) for the front limb hooves. For the hindlimbs, standard aluminum hind shoes were not available, therefore steel trotter race hind shoes with a similar mass were used (Kerckhaert product, 16 × 5 mm, mass of 180–200g).
- Condition 2: forelimb unshod hooves with hindlimb shod hooves (HINDSHOD). Hindlimbs were shod with steel trotter race hind shoes.
- Condition 3: hindlimb unshod hooves with forelimb shod hooves (FORESHOD). Forelimbs were shod with aluminum shoes. This is a frequent condition used for trotter races, in dressage horses and for young saddle horses.
- Condition 4: four unshod hooves (UNSHOD). Although the most frequent winning condition in trotting races, it is forbidden for Thoroughbred races, as it is thought to be associated with increased pain for horses with sensitive feet and we have therefore not used this condition as the reference condition.
- Condition 5: hindlimb egg bar shoes and forelimb aluminum shoes (hEGGBAR),
- Condition 6: hindlimb wide toe shoes with forelimb aluminum shoes (hTOE),
- Condition 7: hindlimb reverse shoes with forelimb aluminum shoes (hREVERSE).

For each horse, the order of the shoeing conditions was randomized. Between each condition, the horses were kept in a stable for at least two hours. All data were collected over two days.

2.5. Kinematic analysis

Hemispheric reflective markers (2 cm in diameter) were placed over selected anatomical landmarks palpated by a single clinician (SC), who is experienced in cervical and back palpation. The landmarks used were as follows: the right side of the neck at the atlas wing (C1) and the body center of the third (C3) and sixth (C6) cervical vertebrae; the top of the spinous process of the sixth (T6), tenth (T10), thirteenth (T13), and seventeenth (T17) thoracic vertebrae; the top of the spinous process of the first (L1) and third (L3) lumbar vertebrae; the tuber sacrale (TS); and the sacro-caudal junction (SC) (Fig. 2). In two tall and obese horses, X-rays were performed to ensure correct placement of the markers at the mid and low-neck areas.

Videos were collected of horse movement in the sagittal plane using a video camera recording at 300 frames per second (Casio Exilim EX-F1, 512×384 pixels), which was positioned perpendicular to the runway. The zoom lens was manually adjusted to produce a 3 m-wide field of view. The camera was placed 13.6 m away from the runway. The runway was calibrated with markers at 30 cm intervals on three lines: one line on the ground in front of the runway, and two lines on the background, at 40 cm and 80 cm above the ground to calibrate the measurements (Fig. 2).

2.6. Data collection

The same experienced handler led all horses along the outdoor arena runway at walk and trot. An assistant followed each horse from behind to check that the horses were walking and trotting as parallel as possible to the background fence and perpendicular to the camera. A trial was considered successful if the horse moved regularly and perpendicularly to the camera. To be sure that speed did not influence kinematic variability, only successful trials within 5 % of the mean speed at walk and trot were included in the analysis. The mean speed for REFSHOD at walk

Fig. 1. Photographs of the shoes used in this the study. Fig. 1.1The reference shoeing (REFSHOD), which consisted of a standard aluminum shoe. Fig. 1.2 Standard steel trotter race shoe. Fig. 1.3 Hind egg bar shoe (hEGGBAR). Fig. 1.4 Hind wide toe shoe (hTOE). Fig. 1.5 Hind reverse shoe (hREVERSE).

Fig. 2. Position of the markers on the back and cervical areas. The markers are surrounded on this picture with red color. Hemispheric reflective markers (2 cm in diameter) were placed over selected anatomical landmarks: the atlas of the wing (C1), the center of rotation of the third (C3) and sixth (C6) cervical vertebrae, at the top of the spinous process of the sixth (T6), tenth (T10), thirteenth (T13) and seventeenth (T17) thoracic vertebrae, at the top of the spinous process of the first (L1) and third (L3) lumbar vertebrae, on the tuber sacrale (TS) and at the sacro-caudal junction (SC).

and trot was 1.53 ± 0.05 m s^{-1} and 3.51 ± 0.17 m s^{-1}, respectively.

For each condition, six successful trials were recorded in walk and trot and data were averaged in subsequent calculations. Only the image showing all the markers from the head to the tail were analyzed, and in the 3 m wide view field it was possible to analyze half of a stride per trial for walk and trot. The beginning of each half stride was defined as the landing of the right or left hindlimb; timepoints R0 and L0, respectively. At timepoints R0 and L0, the landing hoof had stopped moving forwards and entered the mid-stance phase. The end of half a stride was defined as the landing of the contralateral hindlimb to that at R0 or L0. Timepoints defined as R1, R2, R3, R4, and R5 were equally distributed between R0 and R6 during the half of a stride following R0, and timepoints L1, L2, L3, L4 and L5 were equally distributed between L0 and L6 during the half of a stride following L0.

2.7. Data processing

All markers were manually tracked by two operators (EV and AM) using tpsDig2 software (https://fr.freedownloadmanager.org/Windows-PC/tpsDig2.html) to obtain 2D spatial coordinates. Nine dorsal angles were calculated as follows, using Al-Kashi theorem (Fig. 3):

- C3A: dorsal angle between C1, C3 and C6, centered in C3
- C6A: dorsal angle between C3, C6 and T6, centered in C6
- T6A: dorsal angle between C6, T6 and T10, centered in T6
- T10A: dorsal angle between T6, T10 and T13, centered in T10
- T13A: dorsal angle between T10, T13 and T17, centered in T13
- T17A: dorsal angle between T13, T17 and L1, centered in T17
- L1A: dorsal angle between T17, L1 and L3, centered in L1
- L3A: dorsal angle between L1, L3 and TS, centered in L3
- TSA: dorsal angle between L3, TS and SC, centered in TS

We also measured segment angles, which were defined as follows (Fig. 4):

- Cervical angle (CA): angle between the horizontal ground line and the segment C1-C6
- Thoracic angle (TA): angle between the horizontal ground line and the segment T6-T17
- Lumbar angle (LA): angle between the horizontal ground line and the segment L1-TS
- Sacral angle (SA): angle between the horizontal ground line and the segment TS-SC
- Lumbosacral angle (LSA): dorsal angle between the segment L1-L3 and the segment TS-SC
- Thoracolumbar angle (TLA): dorsal angle between the segment T13-T17 and the segment L1-L3
- Thoraco-thoracic angle (TTA): dorsal angle between the segment T6-T10 and the segment T13-T17
- Cervicothoracic angle (CTA): dorsal angle between the segment C3-C6 and the segment T6-T10

The reliability of this method was verified using 10 pilot studies, which were conducted to train the two manual operators and therefore minimize operator bias [26]. The bias for the cursor precision placement using the 2D software tpsdig2 was 2 cm with a 95% confidence interval. The precision to determine R0 and L0 was 2 frames at 300 frames per second at the walk and trot, with a 95% confidence interval.

2.8. Statistical analysis

Left and right-sided measurements (L0 to L6 and R0 to R6, respectively) were compared using a linear mixed-effects model ($P<0.05$). The normality of residuals was assessed after each test by creating a plot of residuals with the qqnorm.lme function on R (AT&T Bell Laboratories, http ://www.r-project.org/). If the data were not significantly different, then the right and left data were combined. If they were significantly different, then they were studied separately. Supplementary Information item 1 shows the results of the comparison between the right and left data for half of a stride in walk and trot.

To compare dorsal and segment angles between shoeing conditions, a linear mixed model was used with horse included as a random factor and shoeing condition included as a fixed factor. The normality of residuals was once again assessed after each test by creating a plot of residuals. This was followed by a Tukey post-hoc test, to identify where the significant differences were. The significance level was set at $P\leq0.05$ and all statistical analyses were performed using R software (R version 3.4.4 2018-03-15).

3. Results

3.1. Effect of shoeing at walk

Table 1 presents the results of the pairwise post-hoc comparison test, with the difference between dorsal and segment angles in the tested shoeing conditions 2–7 and the reference shoeing condition (REFSHOD), at different phases of the stride at walk. Full details on the dorsal and segment angles in the REFSHOD condition at walk and trot are available in Supplementary Information items 2 and 3.

A positive difference between dorsal and segment angles in the tested shoeing conditions 2–7 and REFSHOD indicates that the tested shoeing conditions induced a greater dorsal angle (more flexion) or segment angle than RESHOD. Conversely, a negative difference indicates that the tested shoeing condition induced a lesser dorsal angle (more extension) or a reduced segment angle compared to REFSHOD. C3A, C6A, T6A, T10A, T13A, L1A, L3A and TSA are the dorsal angle centered respectively at C3, C6, T6, T10, T13, L1, L3 and the tuber sacrale. For the segment angles, CA is the cervical angle, TA the thoracic angle, SA the

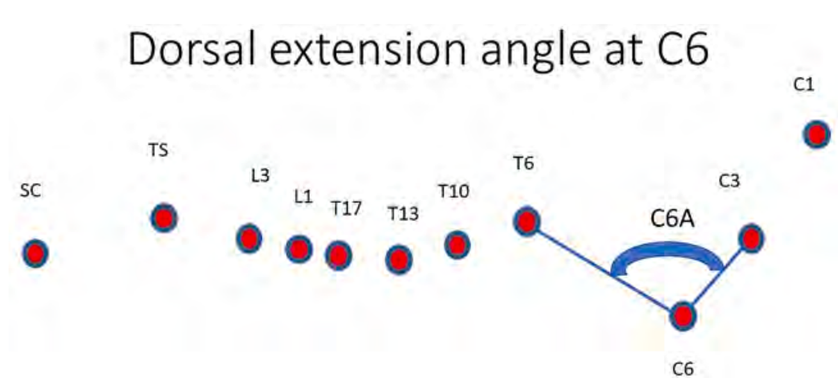

Fig. 3. Illustration of the measurement of the dorsal angle C6A. C3A, T6A, T10A, T13A, L1A, L3A and TSA are the dorsal angles centered respectively at C3, T6, T10, T13, L1, L3 and the tuber sacrale, and measured similarly.

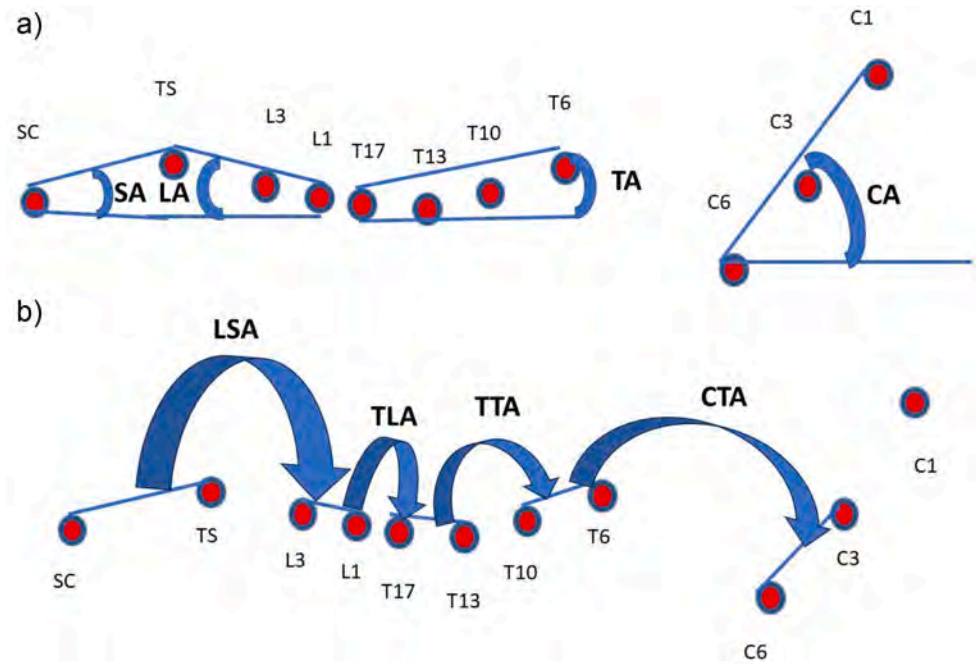

Fig. 4. Illustration of the calculation of the segment angles. Fig. 4a presents the angle between the segment and the horizontal ground line. Cervical angle (CA): angle between the horizontal ground line and the segment C1-C6. Thoracic angle (TA): angle between the horizontal ground line and the segment T6-T17. Lumbar angle (LA): angle between the horizontal ground line and the segment L1-TS. Sacrum angle (SA): angle between the horizontal ground line and the segment TS-SC. Fig. 4b presents the angles between the segments themselves. Lumbo-sacral angle (LSA): dorsal angle between the segment L1-L3 and the segment TS-SC. Thoraco-lumbar angle (TLA): dorsal angle between the segment T13-T17 and the segment L1-L3. Thoraco-thoracic angle (TTA): dorsal angle between the segment T6-T10 and the segment T13-T17. Cervicothoracic angle (CTA): dorsal angle between the segment C3-C6 and the segment T6-T10.

sacrum angle, TLA the thoracolumbar angle and CTA the cervicothoracic angle. REFSHOD: front feet shod with aluminum shoes and hind feet with steel racehorse shoes. FORESHOD: front aluminum shoe and hind feet unshod. HINDSHOD: front feet unshod and hind steel race shoes. UNSHOD: all four feet unshod. Front feet shod in combination with hind egg bar shoes (hEGGBAR), hind wide toe shoes (hTOE) and hind reverse shoes (hREVERSE). The timepoints R0 and L0 are respectively the landing of the right and left hindlimb, and considered as the beginning of the right and left half a stride. The end of right and left half a stride were defined as the landing of the contralateral hindlimb and defined as R6 and L6 respectively. Timepoints defined as R1, R2, R3, R4, and R5 were equally distributed between R0 and R6, and timepoints L1, L2, L3, L4 and L5 were equally distributed between L0 and L6.

Of note, there were no significant differences between the HINDSHOD and REFSHOD dorsal and segment angles. UNSHOD increased flexion at T6 after hindlimb landing by +4.3±1.2° compared to REFSHOD. FORESHOD elevated the neck compared to REFSHOD and was associated with an increased cervical angle (CA) during the entire stride (+6.3 to +6.8±1.7°), and increased cervicothoracic extension (CTA) (-6.7 to -7.8±1.6°) at C6 (-4.0 to -5.6±1.8°) and T6 (-2.5 to -3.9 ±0.9°). FORESHOD also decreased the thoracic angle (TA) relative to REFSHOD (-0.9±0.3°) and increased flexion at the level of L1 (+4.8 ±1.3°) and extension at the level of L3 (-3.2±0.8°) during hindlimb landing.

With regards to the orthopaedic shoeing effects, it was apparent that hTOE elevated the neck compared to REFSHOD via an increased cervical angle (CA) during the entire stride (+5.1 to +6.0±1.7°) and an increased cervicothoracic extension (-6.2 to -7.6±1.6°) at C6 (-4.2 to -6.5±1.8°) and T6 (-3.1 to -3.5±1.2°). hREVERSE also elevated the neck compared to REFSHOD by increasing, at eight time-points of the stride, cervicothoracic extension (-4.7 to -5.6±1.6°) and it was associated with an increased C3 flexion during the first part of the stride (+3.8 to +4.7 ±1.4°). hREVERSE decreased the thoracic angle compared to REFSHOD (by -0.9 to -1.3±0.4°) and increased flexion at the tuber sacrale at landing (+2.0 to +2.1±0.7°). It was also associated with an increased sacral angle (+1.5±0.5°). hEGGBAR elevated the neck compared to REFSHOD and was linked to an increased cervicothoracic extension during the first part of the stride (-5.5 to -5.7±1.8°), located at T6 (-2.5 to -3.4±1.0°). hEGGBAR also increased thoracolumbar flexion (TLA) at landing compared to REFSHOD (+2.9±1.0°) in association to a decreased thoracic angle (TA) (-1.1±0.5°) and an increased T13 (+3.4 ±1.1°), L1 (+3.9±1.3°) and TS flexion (+2.5±0.7°).

3.2. *Effect of shoeing at the trot*

Table 2 presents the results of the pairwise post-hoc comparison, with the difference between dorsal and segment angles in the tested shoeing conditions 2–7 and the reference shoeing condition (REFSHOD), at different phases of the stride at trot.

A positive difference between dorsal and segment angles in the tested shoeing conditions 2–7 and REFSHOD indicates that the tested shoeing conditions induced a greater dorsal angle (more flexion) or segment angle than RESHOD. Conversely, a negative difference indicates that the tested shoeing condition induced a lesser dorsal angle (more extension) or a reduced segment angle compared to REFSHOD. C3A, C6A, T6A, T10A, T13A, L1A, L3A and TSA are the dorsal angle centered respectively at C3, C6, T6, T10, T13, L1, L3 and the tuber sacrale. For the segment angles, CA is the cervical angle, TA the thoracic angle, SA the sacrum angle, TLA the thoracolumbar angle and CTA the cervicothoracic angle. REFSHOD: front feet shod with aluminum shoes and hind feet with steel racehorse shoes. FORESHOD: front aluminum shoe and hind feet unshod. HINDSHOD: front feet unshod and hind steel race shoes. UNSHOD: all four feet unshod. Front feet shod in combination with hind egg bar shoes (hEGGBAR), hind wide toe shoes (hTOE) and hind reverse shoes (hREVERSE). The timepoints R0 and L0 are respectively the landing of the right and left hindlimb, and considered as the beginning of the right and left half a stride. The end of right and left half a stride were defined as the landing of the contralateral hindlimb and defined as

Table 1
Differences (mean ± standard deviation°) between dorsal and segment angles in the tested shoeing conditions versus the reference shoeing condition at walk for timepoints R0 to R6 and L0 to L6. Only values for significant differences ($P<0.05$) are included. * indicates a P value<0.001. Positive differences are highlighted in bold. Negative differences are in italics.

Tested shoeing condition	Dorsal or segment angle	At R0	R1	R2	R3	R4	R5	R6
UNSHOD	No significant differences							
HINDSHOD	No significant differences							
FORESHOD	C6A			-4.0±1.2	-4.1±1.4	-5.7±1.8	-5.0±1.6	
	T6A		-3.5±0.7*	-2.7±0.8	-2.5±0.8		-2.9±0.9	
	L1A		+4.8±1.3					
	L3A		-3.2±0.8					
	CA	+6.6±1.6*	+6.4±1.6*	+6.5±1.6*	+6.7±1.6*	+6.8±1.6*	+6.8±1.6*	+6.3±1.7*
	TA					-0.9±0.3		
	CTA	-6.8±1.5*	-7.1±1.5*	-6.8±1.5*	-6.7±1.6*	-7.2±1.6*	-7.8±1.5*	-7.3±2.0*
hEGGBAR	T6A		-2.5±0.8					-3.4±1.0
	T13A	+3.4±1.1						
	L1A						+3.9±1.3	
	TSA			+2.5±0.7				
	TA							-1.4±0.5
	TLA	+2.9±1.0						
	CTA		-5.7±1.7		-5.5±1.8			
hTOE	C6A			4.2±1.3	-4.5±1.4	-6.5±1.8		-5.4±1.8
	T6A		-3.3±0.7*	-3.2±0.9	-3.5±1.2			
	CA	+5.3±1.6	+5.2±1.6	+5.8±1.6	+5.9±1.6	+6.0±1.6	+5.1±1.7	
	CTA	-6.8±1.5*	-6.7±1.6*	-7.0±1.5*	-7.6±1.6*	-7.6±1.6*	-6.2±1.6*	
hREVERSE	C3A	3.8±1,1		+4.0±1.0*		+4.7±1.4*		
	T10A	+3.1±1.0						
	T13A	-3.2±1.0						
	L1A		+4.0±1.3°					
	TSA	+2.1±0.7	+2.0±0.6					
	TA		-1.1±0.3	-0.9±0.3	-1.0±0.3			-1.3±0.4
	SA		+1.5±0.5					
	CTA	-5.1±1.5		-4.9±1.5	-5.6±1.6	-4.7±1.6		
		At L0	L1	L2	L3	L4	L5	L6
UNSHOD	T6A					+4.3±1.2		
HINDSHOD	No significant difference							
FORESHOD	C6A			-4.0±1.2	-4.1±1.4	-5.6±1.8		
	T6A	-3.5±1.0	-3.5±0.7*		-2.5±0.8	-3.9±0.9*		
	L1A		+4.8±1.3					
	L3A		-3.2±0.8					
	CA	+6.6±1.6*	+6.4±1.6*	+6.5±1.6*	+6.7±1.6*	+6.8±1.6*	+6.8±1.6*	+6.3±1.7
	TA					-0.9±0.3		
	CTA	-6.8±1.5*	-7.1±1.5*	-6.8±1.5*	-6.7±1.6*	-7.2±1.6*	-7.8±1.5*	
hEGGBAR	T6A		-2.5±0.8					
	T13A	+3.4±1.1						
	L1A						+3.9±1.3	
	TA							-1.4±0.5
	TLA	+2.9±1.0						
	CTA		-5.7±1.7		-5.5±1.8			
hTOE	C6A			4.2±1.3	-4.5±1.4			
	T6A		-3.3±0.7*		-3.5±1.2	-3.1±0.9°		
	CA	+5.3±1.6	+5.2±1.6	+5.8±1.6	+5.9±1.6	+6.0±1.6	+5.1±1.7	
	CTA	-6.8±1.5°*	-6.7±1.6*	-7.0±1.5*	-7.6±1.6*	-7.6±1.6*	-6.2±1.6	
hREVERSE	C3A	3.8±1,1		+4.0±1.0°				
	T10A	+3.1±1.0						
	T13A	-3.2±1.0						
	L1A		+4.0±1.3					
	TSA		+2.0±0.6					
	TA		-1.1±0.3	-0.9±0.3	-1.0±0.3			-1.3±0.4
	CTA	-5.1±1.5		-4.9±1.5	-5.6±1.6	-4.7±1.6		

R6 and L6 respectively. Timepoints defined as R1, R2, R3, R4, and R5 were equally distributed between R0 and R6, and timepoints L1, L2, L3, L4 and L5 were equally distributed between L0 and L6.

At trot, there were no significant differences between HINDSHOD and REFSHOD dorsal and segment angles. UNSHOD lowered the neck compared to REFSHOD, and was associated with a decreased cervical angle during the entire stride (-5.6 to -7.5±1.8°), and increased cervicothoracic flexion (+4.8 to +6.4±1.8°) with positive angle differences at C6 (+4.5 to +5.2±1.3°) and T6 (+2.2±0.7°). FORESHOD elevated the neck compared to REFSHOD and was linked to increased cervicothoracic extension (-6.1±1.7°), with notable differences at T6 (-2.2 to -3.6±1.0°). FORESHOD also increased thoracolumbar flexion relative to REFSHOD at hindlimb landing (+2.7±0.9°), increased thoraco-thoracic flexion during the swing phase (R4 and L4) (+2.6±0.8°), and decreased lumbar angle at the beginning of the stance phase (-1.1±0.3°). These results are illustrated in a video, available as Supplementary Information Item 4.

With regards to the orthopedic shoeing effects, hTOE elevated the neck compared to REFSHOD and cervical angles were increased (+4.6 to +5.6±1.6°), with increased cervicothoracic extension (-3.7 to -7.9 ±1.7°) at C6 (-3.7 to -4.8±1.4°). hTOE also increased C3 flexion at landing (+3.8±1.2°) relative to REFSHOD. hREVERSE similarly elevated the neck compared to REFSHOD, and throughout the entire stride cervicothoracic extension was increased (-3.8 to -7.5±1.9°), with notable changes at C6 (-4.2 to -5.0±1.4°) and T6 (-3.1±1.0°). hREVERSE decreased thoracic angle compared to REFSHOD during the swing phase

Table 2
Differences (mean ± standard deviation°) between dorsal and segment angles in the tested shoeing conditions versus the reference shoeing condition at trot for timepoints R0 to R6 and L0 to L6. Only values for significant differences ($P<0.05$) are included. * indicates a P value<0.001. Positive differences are highlighted in bold. Negative differences are in italics.

Tested shoeing condition	Dorsal and segment angle	At R0	R1	R2	R3	R4	R5	R6
UNSHOD	C6A			+4.7±1.4			+4.5±1.2°	
	T6A			+2.2±0.7				
	CA	-5.8±1.4*	-5.6±1.4*	-7.5±1.8*	-6.8±2.0		-6.5±1.5*	-6.5±1.6*
	CTA	+5.2±1.3*	4.8±1.2*	+6.4±1.8			+6.0±1.8	+5.6±1.5
HINDSHOD	No significant differences							
FORESHOD	T6A			-2.2±0.7				
	LA		-1.1±0.3					
	TLA	+2.7±0.9						
	TTA					+2.6±0.8		
hEGGBAR	C6A					-3.5±1.1		
	CTA					-5.7±1.9		
hTOE vs REFSHOD	C3A	+3.8±1.2						
	C6A	-3.9±1.1				-4.7±1.1*	-3.7±1.2	
	CA						+4.6±1.5	
	CTA	-3.7±1.3	-4.0±1.2	-5.7±1.8		-6.0±1.9		
hREVERSE vs REFSHOD	C3A	+4.2±1.2						
	C6A	-4.6±1.1*				-4.9±1.1*	-5.0±1.2*	-4.7±1.3*
	CA						+5.0±1.5	+4.8±1.6
	TA					-1.2±0.4		
	CTA	-4.4±1.2	-3.8±1.2	-5.5±1.8	-6.4-±2.0	-7.5±1.9	-7.0±1.9	-5.8±1.4*
		At L0	L1	L2	L3	L4	L5	L6
UNSHOD	C6A						+5.2±1.3*	
	T6A			+2.2±0.7				
	CA	-5.8±1.4*	-5.6±1.4*				-6.5±1.5*	-6.5±1.6*
	CTA	+5.2±1.3*	4.8±1.2*					+5.6±1.5
HINDSHOD	No significant differences							
FORESHOD	T6A			-2.2±0.7	-3.6±1.0	-3.1±1.0		
	TLA	+2.7±0.9						
	TTA					+2.6±0.8		
	CTA			-6.1±1.7				
hEGGBAR	C6A					-3.5±1.1		
	T6A	+2.9±1.0						
hTOE	C6A	-3.9±1.1		-4.8±1.4°		-4.7±1.1*	-3.7±1.2°	
	CA			+5.6±1.7			+4.6±1.5	
	CTA	-3.7±1.3	-4.0±1.2	-7.9±1.7*		-6.1±1.7		
hREVERSE	C6A	-4.6±1.1*		-4.2±1.4		-4.9±1.1*	-5.0±1.2*	-4.7±1.3*
	T6A				-3.1±1.0			
	CA						+5.0±1.5	+4.8±1.6
	TA				-1.7±0.5	-1.2±0.4		
	CTA	-4.4±1.2	-3.8±1.2			-5.9±1.7	-6.1±1.8	-5.8±1.4*

(-1.2 to -1.7±0.5°) and increased C3 flexion at landing (+4.2±1.2°). hEGGBAR elevated the neck compared to REFSHOD, with increased cervicothoracic extension after landing (-5.7±1.9°), with changes located at C6 (-3.5±1.1°), and increased T6 flexion at landing (+2.9 ±1.0°).

4. Discussion

4.1. Which back and cervical locations were the most affected by shoeing?

The most noticeable shoeing effects were found in the cervical area and cervicothoracic junction: C3A, C6A and T6A represented 5%, 45% and 37% respectively of the total number of significant differences between the different shoeing conditions at walk and trot (Tables 1 and 2, Supplementary Information Items 5 and 6). Analysis of the segment angles results confirmed these findings, with the most statistical differences observed at CA and CTA (Tables 1 and 2, Supplementary Information Items 5 and 6). It is difficult to compare our results to previous studies, which have less extensively studied the cervical and cervicothoracic areas [3,4,7-12,15,16]. However, previous work identified that in showjumpers, osteoarthritis affects nearly 70% of horses, and its prevalence increases with the performance level of the horse [23]. In the neck, the joint moment of the intervertebral motion increases in a cranial to caudal direction, which could explain the high rate of osteoarthritis in the caudal cervical area [20]. Our data also highlight a large range of motion at C6 and T6 (Supplementary Information Items 2 and 3) and demonstrate that the low cervical and cervicothoracic areas have the capability to adapt their position to shoeing. This finding is relevant because shoeing modifications may have a positive or negative effect on the high prevalence of pre-existent low-neck pathologies, osteoarthritis or instability [20-22].

In our study, light-weight shoes (saddle horse aluminum shoe and steel race horse shoe, with similar weight) induced very few effects on the thoracic area, especially at T10, in contrast to previous studies conducted on an instrumented treadmill, which demonstrated that internal or external factors largely influenced the kinematics at T10 [5,7,9,12,15,16,19]. These differences may be explained by the differences in experimental set-ups; for example, treadmill versus over ground locomotion, and differences in the kinematic analysis systems utilised. The three-dimensional motion capture system used in these previous studies facilitates precise calculations, and should have been capable of detecting subtle, yet statistically significant, differences at T10 if they were present. Although equine back kinematics in the thoracic area have not been found to be greatly different between treadmill and over ground locomotion at the trot [3], fore- and hindlimb retraction decreases [27] and thoracolumbar extension increases [19] on a treadmill compared to over ground locomotion. These differences between limb and back kinematics during treadmill versus over ground locomotion could explain shift in focus from of the most affected thoracic area being T10 in previous treadmill studies [5,7,9,12,15,16,19] to T6 in our study.

Alternatively, the different regions of the thoracic area may have differing sensitivity to external factors, with T6 being more sensitive to shoeing changes than T10.

It is also very difficult to maintain a constant speed at the walk and the trot in hand, and this is a limitation of overground motion studies. However, in an attempt to reduce this bias, we had excluded trials with a speed higher or lower than the mean speed by ± 5%. Another limitation of our study could be the short adaptation time (a few hours) between the shoeing modifications and data acquisition. This meant we could only observe the short-term effects of shoeing. In other studies, various experimental setups with different adaptation times have been used, from several minutes [28] to days [29,30] and weeks [31]. Deciding which protocol is the best is difficult because longer adaptation times can also introduce bias by inducing hoof shape modifications [32], which have a direct impact on equine locomotion [33]. It is also possible that marker displacement due to skin movement may have biased the data, and this was not further investigated; although this effect expected to be small because there is tight skin coverage over the back of horses, and, overall, marker mobility is low [34].

4.2. Gait effect on the back and cervical kinematics

Trot had a proportionally greater effect on cervical and cervico-thoracic angles and a smaller effect on thoraco-thoracic, thoracolumbar and lumbosacral angles, compared to walk. Similar findings were observed for the dorsal angle. In comparison to walk, trot is a more active gait and is associated with increased cervical and back muscular stabilization and a smaller range of motion [9,11,18-20]. This muscular stabilization could damp the impact of external factor effects on the back kinematics and could explain the reduced influence of shoeing condition at trot versus walk on the thoracolumbar and lumbosacral areas observed in our study.

4.3. Influence of the reference shoeing condition (supplementary information item 5 and 6)

At walk and trot, the pairwise post-hoc comparisons showed no significant differences in dorsal and segment angles between HINDSHOD and UNSHOD, but there were several significant differences in angles between FORESHOD and UNSHOD, particularly at walk. This indicates that shoeing forelimb hooves had a greater influence on cervical and back movement compared to shoeing hindlimb hooves. Previous work has also found that shoeing forelimb hooves has a stronger effect on limb kinematics compared to shoeing hindlimb hooves [24]. Moreover, when we compared FORESHOD and HINDSHOD to REFSHOD (Tables 1 and 2), the conclusions were similar: HINDSHOD versus REFSHOD induced no significant effect, and FORESHOD versus REFSHOD induced many effects, with nearly the same results at the cervicothoracic junction as when we compared FORESHOD to UNSHOD. It is possible that the weight imbalance between fore- and hindlimbs, with more weight on the forelimbs at walk and trot gaits, is a key factor affecting the horses' locomotion, especially at the cervicothoracic junction. Therefore, a horse's head and neck position and consequently its center of mass position [7,18,20], may experience the greatest sensitivity to shoeing effects. Moreover, the relative positioning of muscle mass directly proximal to the front and hindlimbs may be relevant. In hindlimbs, the rump represents nearly 40% of the total body mass, whereas the forelimb extrinsic muscles represent only around 4% of the total body mass [35]. Therefore, the large rump mass could constrain the impact that shoeing has on the back and cervical regions. Finally, we could also hypothesize that shoeing the forelimb hooves could also have a stronger effect simply because of its proximity to the neck and back (especially thorax) regions.

Our results showed that at walk FORESHOD induced a decreased thoracic angle (TA), increased flexion at the level of L1 and increased extension at the level of L3, compared to REFSHOD. At the trot, when compared to REFSHOD, FORESHOD increased thoraco-thoracic (TTA) and thoracolumbar (TLA) flexion and decreased lumbar angle (LA). In the FORESHOD condition the thoracolumbar junction was flexed at most time-points of the stride and lumbar extension was increased at the beginning of the stance phase. These findings could be relevant for back rehabilitation at walk and trot gaits, depending on the location of back pain. A previous study comparing FORESHOD and REFSHOD [24] demonstrated that FORESHOD increased stifle and hip extension at many time points in the stride at walk and trot, which could be related, according to the bow and string model [5,7,10], to the increased lumbar extension observed in our study. This previous study [24] also demonstrated that FORESHOD increased forelimb fetlock extension at mid- and end-stance phases compared to REFSHOD, and increased the area under the extension curve in the forelimb fetlock at both walk and trot. Anatomical features may be relevant considerations that will help to explain the relationship between the increased forelimb fetlock extension observed previously [24] and the reduced thoracic angle (TA) and increased mid thoracic (TTA) and thoracolumbar (TLA) flexion observed in our study. For example, in the forelimb, the Serratius Ventralis Thoracis (SVT) muscle is the strongest extrinsic muscle, with short fascicles arranged at about 45° to the long axis of the muscle which may generate forces opposing gravity. The role of the SVT muscle is mainly to suspend the limb from the trunk, to raise the thorax and to promote limb protraction via scapular rotation [36]. We hypothesize that the increased forelimb extension with FORESHOD, compared to REFSHOD [24], may be related to increased SVT muscle activity [10]. Increased SVT muscle activity would, due to its proximo dorsal-disto caudal orientation [36], decrease the thoracic angle and consequently increase mid-thoracic (TTA) and thoracolumbar (TLA) flexion, as observed in our study. Further direct measures of the SVT muscle activity using electromyography are necessary to confirm this hypothesis.

At trot, the UNSHOD condition lowered the neck (CA), with an increased cervicothoracic flexion (CTA) localized at the cranial thoracic (T6A) and low cervical (C6A) positions, compared to REFSHOD. Previous work has demonstrated that REFSHOD, with a steel shoe (500-600 g), can induce a more animated gait when compared to UNSHOD [25]. Also, the addition of weighted boots (600 g) on fore- and hindlimbs can induce a 6.7% increase in metabolic rate at trot [37]. The apparent reduction in energy consumption for UNSHOD, compared to REFSHOD, could be related to a decrease in muscle activity and probably also less passive elastic energy being stored and released in limbs, cervical and withers area. In the cervicothoracic area, the three cervical fasciae and the nuchal ligament play a major role in energy storage and their actions induce a cervical extension [20]. This elastic passive energy mechanism could be less efficient for UNSHOD, in comparison to REFSHOD, which would explain the lower head and neck positions observed at trot for UNSHOD in our study.

In conclusion, during a locomotor clinical examination, a horse's shoeing condition should be considered. An unshod horse is expected to present an increased cervicothoracic flexion, a more horizontal thoracolumbar area and a less animated gait [25], than a shod horse. Moreover, a horse only shod on the forelimbs (FORESHOD), will present a increased cervicothoracic extension and more thoracolumbar flexion than UNSHOD or REFSHOD conditions. It is important to recognize that these are normal physiological clinical signs and should not be considered as a pathological condition.

4.4. Influence of the orthopedic hind shoes

4.4.1. Role of the contact surface area

At walk and trot, the three hindlimb orthopedic shoes (hTOE, hREVERSE and hEGGBAR) increased the cervicothoracic extension, when compared to REFSHOD. For all three orthopedic hind shoes, this increased cervicothoracic extension appears to be related to an increased caudal cervical (C6A) extension at the trot. Moreover, there was increased mid-cervical flexion (C3A) for hREVERSE compared to

REFSHOD at walk, and also for hTOE and hREVERSE compared to REFSHOD at trot. We propose that the surface area of the shoe in contact with the ground had more effect on the cervicothoracic and cervical mobility than the type of hindlimb orthopedic shoe. For example, the contact surface area of the orthopedic aluminum shoes is nearly 200% more than the steel reference shoe (Fig. 1). We also note that there were no significant differences at the cervical and cervicothoracic areas for the hTOE and hREVERSE conditions (Supplementary Information items 5 and 6). Previous kinematic clinical studies have also demonstrated similar results when comparing hindlimb wide toed shoes to reverse shoes, with no difference in joint angles observed in the hindlimb [24] and neither when applied on the forelimb, except for the front coffin joint [38].

In comparison to REFSHOD, at walk hEGGBAR was the only orthopedic shoe that increased the thoracolumbar flexion during landing. At trot, FORESHOD also increased thoracolumbar flexion during landing when compared to REFSHOD. With hEGGBAR and FORESHOD, the increased surface area of shoes on the hindlimb hooves relative to REFSHOD could play a key role in increasing thoracolumbar flexion. Limb kinematics were also similarly affected for FORESHOD and hEGGBAR, when compared to REFSHOD, with increased stifle and hip extensions [24]. Finally, our findings could be relevant for the rehabilitation of horses with back pain at slow gaits, and when there are modifications applied to the head and neck position; for example, in riding horses; especially those in working in dressage.

4.4.2. Effects of different types of orthopedic hind shoes

At walk and trot, our results showed that hind shoes with heel coverage (hEGGBAR and hREVERSE) induced a flatter thoracic angle than REFSHOD or hTOE. These results may be explained as follows. Increased forelimb extension and protraction with hREVERSE shoes compared to REFSHOD or hTOE [24] may be counteracted by SVT muscle contraction, as discussed above, which will in turn lead to a flatter thoracic angle. However, electromyography is required to confirm the effect of shoeing on SVT muscle activity. It is also interesting to note that an association between forelimb protraction and a flatter thoracic angle has been observed in ridden horses, when compared to unridden horses [39].

Our data also showed that hindlimb shoes with heel coverage increased lumbosacral flexion. In hindlimbs, it has previously been demonstrated that hindlimb shoes with heel coverage increase stifle and hip extension [24]. This increased hip extensor activity could help to explain the increased lumbosacral flexion. To explain the relationship between the type of orthopedic hind shoe and its effect on stifle, hip and lumbosacral flexions, it is helpful to consider previous work that has explored the relationship between the orientation of the hindlimb ground reaction force (GRF) vector and the activity of hip and stifle muscles. On hard ground at walk, in the first 24 % of the stride (0% of the stride = hindlimb landing), the GRF vector passes in front of the stifle and hip center of rotation and induces an active hip extension and a passive stifle extension [40]. After the initial 24 % of the stride, the GRF vector passes behind these two joints, and induces a passive hip extension and a passive stifle flexion [40]. It was previously demonstrated that reverse and egg bar shoes caudally displace the center of pressure in comparison to classic shoes [38,41]. This center of pressure displacement could modify the origin of the GRF vector, and potentially redirect the GRF vector more cranially, as has previously been observed in forelimbs [42]. In turn, this GRF vector, if directed in a more cranial direction, could modify stifle, hip and lumbosacral flexion-extension.

Alternatively, the relationship between lumbosacral flexion and hindlimb heel shoe coverage could be linked to the acute breaking induced by hREVERSE at landing [24], whereby the lumbosacral flexion is a response acting to dissipate impact forces. Importantly, another clinical study demonstrated a positive correlation between long toes in hind feet and gluteal pain [43] and postulated that an increased lever arm between the GRF vector position on the hind feet and the moment arm at the fetlock plantar aspect could be responsible for the pain [43]. When hindlimb heels are covered by shoe material, this same lever arm is likely to be reduced, therefore it is to be expected that such shoes may also have an influence on gluteal pain, particularly given their known impact on lumbosacral flexion we have identified. Further studies are required to confirm this.

In conclusion, hindlimb orthopedic shoes can influence equine back and cervical kinematics. In comparison to REFSHOD, the three hindlimb orthopedic shoes trialed increased cervicothoracic extension; HREVERSE and hTOE increased the flexion at C3; and hEGGBAR increased thoracolumbar flexion. Consequently, these effects on back and cervical areas should be considered when veterinarians and farriers consider hindlimb orthopedic shoes for treatment or rehabilitation of soft tissue or joint pathologies in the hindlimb.

5. Conclusion

This study has revealed some of the effects that different shoe types can have on equine back and cervical kinematics. Barefoot horses showed a lowered neck position when compared to shod horses, which could have relevance for impacting riding styles and should also be considered during a clinical examination. In comparison to REFSHOD, shoeing only the forelimb hooves with saddle horse aluminum shoes, induced a similar effect to the combination of aluminum egg bars on the hindlimbs and saddle horse aluminum shoes on the forelimbs, with an observed elevated neck and a more thoracolumbar flexion. This could be relevant for cervical and back treatment as well as rehabilitation.

Ethics in publishing statement

This research presents an accurate account of the work performed, all data presented are accurate and methodologies detailed enough to permit others to replicate the work.

The experimental design was approved by the Direction Départementale de la Protection des Populations du Calvados (France). The agreement experimentation number for the Centre Hospitalier Vétérinaire Equin de LIVET (experimentation center) was A14214016. The agreement procedure was registered by the DDPP of Calvados (France) under the number R-45GRETA-F1-04.

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CRediT authorship contribution statement

S. Caure: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation. **P. Dendauw:** Investigation, Formal analysis. **L. Thesee:** Formal analysis, Data curation. **E. Villedey:** Formal analysis, Data curation. **A. Malinvaud:** Methodology. **M. Cousty:** Supervision. **V. Prie:** Writing – review & editing. **K. Horan:** Writing – review & editing. **R. Weller:** Supervision.

Declaration of competing interest

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jevs.2024.105194.

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Traumatic Muscle Injuries

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KEYWORDS

• Delayed-onset muscle soreness • Exercise-induced muscle damage
• Fibrotic myopathy • Muscle strain

KEY POINTS

- Athletic horses can have exercise-induced intrinsic muscle trauma such as delayed-onset muscle soreness and muscle injury such as muscle tears.
- Presentation can range from elevation in serum muscle enzyme activities to overt lameness, and evaluation of muscles should form part of a thorough musculoskeletal examination.
- Treatment and prevention of muscle injuries are optimally performed with a veterinarian-physical therapist multidisciplinary team approach.
- Treatment strategies are usually aimed at reducing pain and restoring maximal function with protection, optimal loading, ice, and compression used rather than rest; even for higher-grade injuries, conservative reintroduction to exercise is recommended to hasten return to function.
- Prevention strategies involve stretching, warming up, and appropriate strength and skill training for the horse's athletic discipline.

INTRODUCTION

Traumatic muscle injuries can present with signs ranging from acute pain and lameness in a localized region to unexplained elevations of muscle enzymes on routine blood tests with or without poor performance. Although any horse can be exposed to external (extrinsic) muscle trauma and muscle damage during procedures such as anesthesia, most other causes of traumatic muscle disease will occur in athletic horses. These traumatic muscle injuries usually involve internal (intrinsic) trauma, and particularly occur in athletic horses exercising at higher intensities, at unaccustomed workloads or performing work requiring sudden acceleration, deceleration, and/or direction changes.

Extrinsic muscle trauma would include open or closed injury caused by impact or falls resulting in contusion or laceration. It also includes damage associated with intramuscular injections, which should not be discounted when evaluating a horse for

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muscle pain or muscle enzyme elevations. Anesthetic myopathies are covered in the Douglas Castro and Stuart Clark-Price's article, "Anesthesia and Myopathies of Horses," in this issue.[1] Therefore, this article focuses on intrinsic traumatic muscle injuries in the athletic horse.

Intrinsic traumatic muscle injuries in human athletes are well known and can be broadly divided into exercise-induced muscle damage, including delayed-onset muscle soreness (DOMS) and muscle injury, including muscle and musculotendinous tears.[2,3] Although far less studied, there is evidence that similar intrinsic traumatic muscle injuries occur in equine athletes.[4,5]

Presentation of exercise-induced muscle damage in horses is often vague. Although some horses may show overt stiffness and diffuse muscle pain on palpation, others may show poor performance, and others show no apparent clinical signs. Some horses are diagnosed following routine blood testing, where mild, unexplained elevations of creatine kinase (CK) and aspartate aminotransferase (AST) activities are recognized. Other possible causes of elevated muscle enzyme activity combined with mild generalized muscle pain including recurrent exercise-associated myopathies (see Stephanie J. Valberg's article, "Sporadic and Recurrent Exertional Rhabdomyolysis," in this issue) and nonexertional myopathies such as viral myalgia should be ruled out.[6]

Presentation of muscle injury depends on the severity and location, but often presents as lameness associated with focal intense pain in the associated muscle. Severe, high-grade injuries may present with swelling and palpable deficits in the muscle.[5]

This article discusses intrinsic traumatic muscle injuries in the horse, with review of relevant equine literature and reference to relevant literature in other species.

GENERAL RESPONSE OF MUSCLE TO INTRINSIC TRAUMA: DAMAGE AND HEALING

Unlike extrinsic or external muscle trauma, intrinsic muscle injuries result from excessive stresses or strains on skeletal muscle without direct impact.[3] Stresses can be defined as for force per unit of tissue, and strains as the relative length change or deformation of muscle tissue under stress.[3,7] There are well-known risks for intrinsic muscle injuries such as the anatomy and orientation of muscles, the fiber type, and the type of exercise, in particular stress during lengthening or eccentric exercise,[3] which will be discussed. Most of what is known about muscle injury and repair has been derived from two animal models of muscle injury: eccentric contraction injury models and contusion models.[3]

The pathophysiology of muscle injury involves initial degeneration and necrosis, retraction of the ends of the myofibers, followed by infiltration of inflammatory cells, regeneration and repair, and finally remodeling, revascularization, reinnervation, and fibrosis.[8,9] In higher-grade injuries, there will be rupture of surrounding blood vessels leading to hematoma and hypoxia resulting in full fiber necrosis.[3] Muscle fibers have remarkable regenerative capacity, especially when satellite cells (a type of stem cell) can migrate from their usual site between the muscle sarcolemma and basement membrane to the site of necrosis.[9] Muscle can usually repair focal damage intrinsically via myonuclei, but requires satellite cell migration for new myofibers following full myofiber necrosis[3] (**Fig. 1**). If satellite cells are absent, repair can be characterized by the accumulation of fat and fibrous tissue instead of myofibers.[3] Basement membrane damage also results in more extensive fibrosis that can impede revascularization and reinnervation.[9] Unimpeded muscle regeneration is usually mostly complete 3 to 4 weeks after injury, but can take up to several months.[3,9,10]

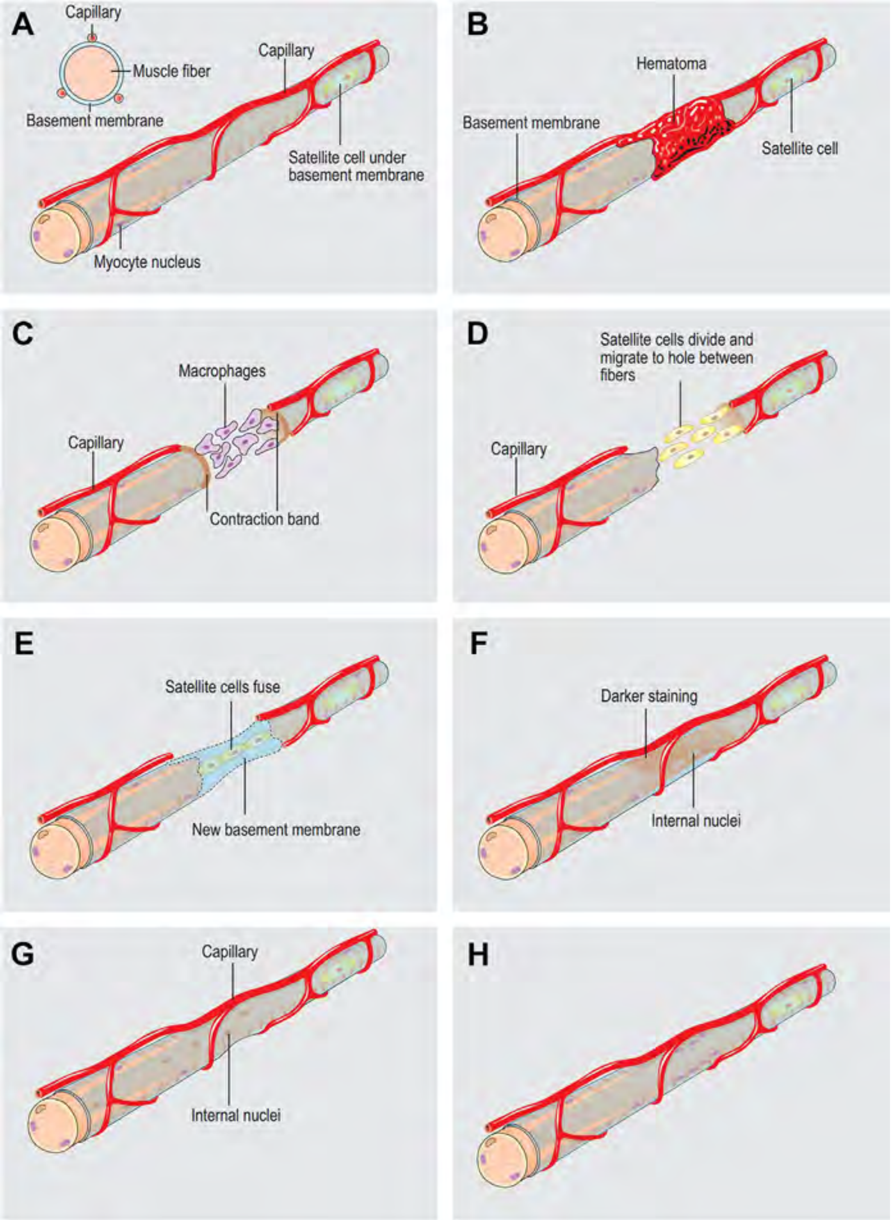

Fig. 1. Repair and regeneration in muscle following damage and disease. (*A*) Normal muscle fiber surrounded by a basement membrane that covers the occasional satellite cell together with a rich network of capillaries. (*B*) Damage causes myofiber disruption that may or may not involve the basement membrane and hematoma formation, depending on severity. (*C*) Myofiber stumps retract and the ends become plugged with the contraction band, made of sarcomeric proteins. Macrophages migrate into the (remnants of the) basement membrane cylinder within the first 24 hours and engulf and remove damaged tissue. (*D*) Satellite cells become activated (12 to 24 hours following injury), proliferate, differentiate into myoblasts and migrate to the damaged region. By days 2 to 3, satellite cells align and bridge the gap,

EXERCISE-INDUCED MUSCLE ENZYME RELEASE

It is important to factor in the expected magnitude and duration of muscle enzyme increase following exercise before interpreting elevations in muscle enzyme activity. Increases in serum CK activity after exercise without intrinsic muscle damage have been attributed to a transient increase in cell membrane permeability associated with the metabolic perturbations of exercise, and values typically return to baseline by 24 hours.[11,12] However, this depends on the fitness of the horse and the intensity and duration of exercise.

In general, clinically significant increases in serum CK activity following short-duration submaximal exercise are not expected. Trotting exercise for 40 minutes on a treadmill at 5 meters per second without incline was not associated with increased serum CK or AST activities.[13] However, serum CK activity has have been shown to increase up to threefold following short-term high-intensity exercise in Thoroughbreds on a treadmill[11] or racing[14] and following showjumping competition,[13,15] returning to baseline within 24 hours.

Serum CK activity will increase during endurance riding competition in the absence of clinical signs of muscle injury, with a doubling observed by around 20 km (12.5 miles) into an event and further increases expected with greater distances covered.[16,17] At the end of 80.5 km (50 miles), mild-to-moderate increases of serum CK activity (<4000 U/L) are observed in many clinically normal horses.[18] Although horses in these studies were apparently healthy, and without significant metabolic alterations, it is difficult to know how many of these elevations are associated with exercise-induced muscle damage. A decline in CK over the course of multiday endurance events has also been observed, potentially suggesting adaptation to consecutive days of effort.[17]

Conditioning has been shown to attenuate postexercise muscle enzyme increases,[11] and there are typically no residual effects of training in normal horses on serum CK and AST activities.[12] However, individuals can display increases caused by injury, disease, overtraining, or cumulative muscle damage that can become evident during a training season.[4,12]

EXERCISE-INDUCED MUSCLE DAMAGE

Pathophysiology and Risk Factors

Exercise-induced muscle injury or DOMS has been well-described in the human literature and is associated with excessive stresses and strains on the muscle resulting in ultrastructural damage and pain.[19,20] Stresses and strains are greatest in muscle contracting from a lenghtened position, or while lengthening (eccentric contraction) than those contracting in a neutral position (isometric contraction), or while shortening (concentric contraction). Most of the research in exercise-induced muscle injury using animal models or people has utilized eccentric exercise.[3] When the muscle is contracting while lengthened, it is at greater risk of injury because of the biophysics of the myosin cross-bridge interaction with actin filaments.[3] Injury is first observed as

fusing between the fiber stumps (*E*). The process continues over the next week as narrower, more differentiated myotubes with internally located nuclei form (*F*) followed by more mature myotubes (*G*). Nuclei return to the normal subsarcolemmal location over several months (*H*). (*Reproduced (with permission) from* Piercy RJ, Rivero JL. Muscle disorders of equine athletes. In: Hinchcliff KW, Kaneps AJ, Geor RJ. Equine sports medicine and surgery: basic and clinical sciences of the equine athlete. 2nd edition. 2014:109-143.)

a disruption in the normal striations of muscle on electron microscopy, in particular at the Z disc, often called Z-band streaming, and is greatest in type II muscle fibers, which have the narrowest and weakest Z-bands, as well as greater force production.[20,21] The disruption is concurrently associated with disruption of the intermediate filament protein, desmin, which unlinks the sarcomere from the rest of the myofiber (**Fig. 2**).[3] Inflammation follows the disruption of the sarcomeres, causing pain and elevated serum CK activity, which peaks 24 to 72 hours following the exercise bout and lasts up to 5 days.[21]

It is important to note that, despite the name, DOMS does not just cause soreness but is well established to result in a sustained loss of muscle force production capacity, which happens immediately after exercise, before the onset of muscle pain.[19] Reported decrements in force production in human athletes with DOMS are between 50% to 65% of baseline.[2,19,22] In people, force generation has also been observed to recover when muscle pain is still at its most severe.[19] Translated to the athletic horse, while mild pain may not be readily apparent, loss of force production could result in poor performance and elevated CK.

Delayed-Onset Muscle Soreness in Horses

DOMS is virtually unreported in the veterinary literature but is likely to occur in athletic horses as it does in people and animal models. In people, as bipeds, eccentric exercise is often performed as downhill running or stepping down (affecting the quadriceps muscle group). However, in quadrupeds such as the horse, each gallop stride involves a mixture of concentric and eccentric muscle contractions. Consider the lengthened position of the triceps muscles and biceps femoris on ground contact during galloping or when landing or taking off from a jump; these muscles contract to stabilize the limb while the muscles are still extended (lengthened) and then further contract to provide the force for the next stride. Unaccustomed exercise that could potentially cause

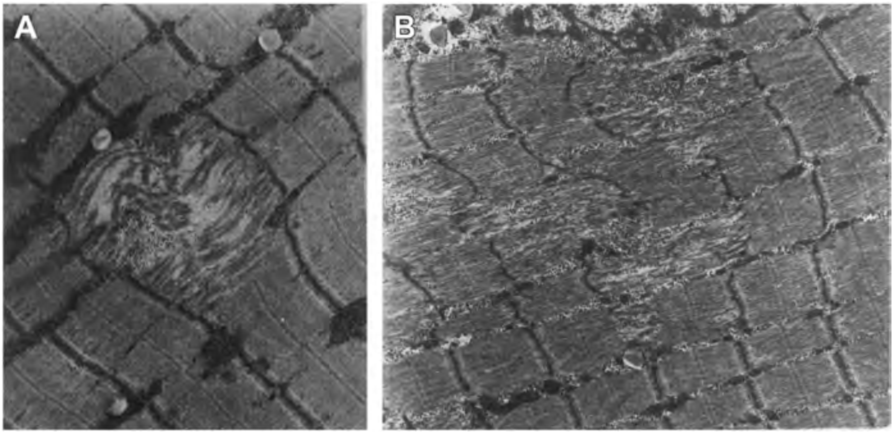

Fig. 2. Electron microscopy images of human muscle following eccentric exercise (magnification x19,000). (*A*) Focal area of disruption immediately after eccentric contractions affecting 1 sarcomere and 2 adjacent myofilaments. The myofilaments are disorganized, and there is displacement of the z-lines. (*B*) Extensive area of sarcomere disruption. (*Reproduced (with permission) from* Newham DJ, McPhail G, Mills KR, Edwards RH. Ultrastructural changes after concentric and eccentric contractions of human muscle. Journal of the neurological sciences. 1983;61(1):109-22.)

soreness can include backing (such as during training of young horses) and introduction of a new exercise such as jumping.

There have been unexplained elevations of muscle enzymes reported in 2-year-old Thoroughbreds commencing training for the first time that were hypothesized to be caused by DOMS.[4] These increases were greatest when the intensity of exercise increased (canter and galloping introduced) and were detected as increased serum activities of AST on monthly samples. Based on these data, DOMS might be occurring in horses starting a new exercise or activity, increasing in level of work effort, or exercising when compensating for lameness.

Overtraining and Cumulative Muscle Damage

Intrinsic exercise-induced muscle damage may also be associated with long-term training or overtraining. Increases in serum activities of AST have been reported in horses that were overtrained[23] and correlated with cumulative training days.[4] These increases are mild, with serum AST activity 2 to 4 times baseline values, and may be reflective of chronic low-grade cumulative muscle damage. This could also be reflective of intermittent episodes of muscle damage, either caused by changes in workload (unaccustomed exercise), or other factors such as compensation for lameness increasing recruitment of alternative muscle groups. Overtraining may also cause incoordination and susceptibility to injury, which could lead to increase stresses or strain on muscles.[23]

MUSCLE INJURY

Muscle ruptures (tears) result from excessive stresses (force per unit of tissue) and/or strains (a measure of deformation of the tissue or relative length change) that exceed the load-bearing capacity of the muscle tissue, leading to damage.[3] Muscle tears are remarkably common in human athletes, constituting approximately one-third of all injuries in soccer and football.[2] It has been shown in human athletes that risk factors for muscle tears are muscles that cross multiple joints (because of the relatively short fibers in these muscles), such as the hamstring, gastrocnemius and rectus femoris, and the presence of type II fibers.[2,3] Intrinsic muscle injury in human athletes often occurs near the musculotendinous junction but also at the origin and insertion of the muscle.[3]

The classic classification system of acute muscle injuries is[24]

1. Grade I injury (often called muscle strains) involving only a few fibers
2. Grade II injury or partial tears
3. Grade III injury or complete tears or rupture of the muscle

Other classification systems have been proposed in human athletes, taking into consideration the location of the injury, the grade, and the mechanism of the injury. In particular, it is determined if the lesion involves the muscle belly, insertion or origin, or musculotendinous junction, since injuries involving the tendinous portions often have longer recoveries and greater reoccurence.[24,25] One proposed system is called the MLG-R, mechanism, location, grading and reinjury for human athletes.[25] However, based on the relatively limited literature and characterization of muscle injury in horses, the classic classification system combined with the location or structure involved is likely to be most useful.

Muscle Injury in Horses

Despite how common intrinsic muscle injury is in people, reports of muscle tears and ruptures are relatively scarce in horses.[5,26,27] This is most likely because of a lack of recognition and the difficulty in diagnosis, especially in lower grades of injury. In a retrospective study of 1,512 horses that had undergone scintigraphy of the pelvis in 1 institution over a 7-year period, 128 horses had increased radiopharmaceutical uptake, and 34 (26.6%) had uptake that involved the skeletal muscle.[28] Of these, 9 involved a focal area of uptake in the middle gluteal and in 3 the semimembranosus and semitendinosus suggestive of a discrete muscle tear.[28]

The most common muscles affected with intrinsic muscle injury in athletic horses depend on the type of exercise performed. In 1 study, 5 of the 8 cases occurred in racehorses in race training involving the gluteus medius (3 horses), gracilis (1 horse) and semitendinosus (1 horse) muscles.[5] In 1 of these cases (with a partial tear of the semitendinosus muscle), a diagnosis was only made on scintigraphy of the pelvis.[5] In another case series, 2 barrel racing horses presented with gracilis muscle tears, both occurring during turning around a barrel during competition.[27] Another study reported muscle tears causing lameness in 14 horses of a variety of breeds and disciplines, but 11 of these had a history of extrinsic trauma, and 3 of them had suspected extrinsic muscle trauma.[26] As a result, no pattern of muscle involvement was found for fore or hindlimb muscles, likely reflecting the inciting cause (extrinsic trauma).

Diagnosis of Muscle Tears in Horses

Muscle injury should be a differential diagnosis for lameness in horses, especially intrinsic injury when there is hind limb lameness in athletic horses. Careful history taking might reveal a point of onset during exercise.[27] Palpation of the hamstring muscles and medial thigh as well as the middle gluteal muscles should form part of a routine lameness assessment. DOMS is an important differential diagnosis for grade I injuries (muscle strain injury), but muscle injuries resulting in grade I tears are more localized on palpation and likely to be asymmetric. Grade II and III partial and complete muscle tears may present with localized swelling, pain, or even a palpable defect.[5,26,27] Depending on when the tear occurred, serum muscle enzyme activities may be increased; this is inconsistent, however, and in many cases increases are mild.[5,26,27]

Ultrasonography is an effective imaging technique for muscle injuries, to help confirm the presence and establish a grade, although if the injury occurs at the origin or insertion of a muscle, radiography should also be considered to help determine if there has been an avulsion fracture at the site of the injury.[26] Identification of the location of the injury, especially determining involvement of the musculotendinous junction, will aid in determining recovery times, as injuries involving this region will have longer recovery times.[25] Nuclear scintigraphy, if available, can also identify muscle tears,[5,28] and conversely, increased radiopharmaceutical uptake in the skeletal muscles of horses being investigated for lameness should prompt further investigation for intrinsic muscle injury. This might include thorough palpation, serum muscle enzyme assessment, muscle ultrasound, and potentially muscle biopsy.[5]

Fibrotic Myopathy

Despite the scarcity of reports regarding acute intrinsic muscle injury in horses, one chronic consequence, fibrotic myopathy, has been commonly reported.[29] Typically affecting the semitendinosus, semimembranosus, and gracilis muscles of Quarter Horses performing exercise involving turning and sliding stops using the hindlimbs, fibrotic myopathy produces a characteristic gait, observed during the swing phase, involving a shortened cranial phase and a rapid caudal movement of the limb during the caudal phase where the affected hindlimb appears to slap to the ground.[29] One report has documented the progression from acute muscle tear in a barrel racing

Quarter Horse to fibrotic myopathy over a 3-month period.[27] Although often reported to occur after repeated muscle injury, this report[27] followed a single severe (grade III) muscle tear, which, based on the severity of damage, likely resulted in fibrotic repair.[3]

TREATMENT OF INTRINSIC TRAUMATIC MUSCLE INJURY

Treatment of intrinsic muscle injury in horses has largely been translated from treatment of human athletes because of the limited data available for horses. Treatment is optimally performed with a veterinarian-physical therapist multidisciplinary team approach.

Exercise-Induced Muscle Damage

Following exercise-induced muscle damage, treatment strategies are usually aimed at reducing the pain and restoring maximal function, but many of the treatments can also be used to prevent DOMS.[21] These include cryotherapy, stretching, nonsteroidal anti-inflammatory drugs (NSAIDS), compression, and massage.[21] Use of NSAIDS has been studied extensively in people with DOMS, both as a treatment and preventive strategy. However, there have been conflicting results, with very high doses shown to delay recovery.[21] In horses, NSAIDS should be used for analgesia as required at analgesic doses. Exercise can also be used as a treatment to reduce pain,[21] and although intense and unaccustomed exercise is not recommended, continuation of light controlled exercise and muscle loading during recovery is recommended (see Melissa R. King and Sandro Colla's article, "Muscle Rehabilitation Techniques and Prevention of Injury," in this issue).

Muscle Injury

Treatment of intrinsic muscle injury depends on the grade and location. In general, recovery is rapid with low-grade injuries, and similar principles to the treatment of DOMS can be applied. Treatment strategies in human athletes can be defined by the acronym POLICE (protection, optimal loading, ice, compression and elevation).[8] An earlier acronym RICE, with the R indicating rest, has been superseded by evidence showing early exercise therapy and progressive loading through an active approach improve recovery times.[3]

Elevation of the injury is impractical in horses, but the other components of these approaches apply. Application of ice can limit bleeding by promoting vasoconstriction, and reduces edema, swelling, and pain.[2] Ice can be applied 2 to 3 times daily during the first 3 to 5 days.[2] Where compression is practical, it can be applied to limit intramuscular blood flow into the affected area, and hence edema and swelling.[2]

There remains a lack of evidence for the optimal balance in mechanical stimuli to promote recovery, although in people, pain (or pain-free exercise) is commonly used to guide rehabilitation programs.[3] This may not be as easily translatable to the horse, especially for milder pain in the later stages of recovery that does not reliably manifest as lameness, or in horses receiving analgesic drugs, so conservative reintroduction to exercise under close observation is recommended.

Treatment programs for traumatic muscle injuries should not only include the affected muscle, but also muscles that work synergistically with that muscle to reduce the work placed on the affected muscle and protect it.[3] Timeframes for recovery of muscle injury depend on injury grade and location but a proposed timeline is

- In the acute phase (0–14 days), the primary goal is to protect the muscle, and treatment will involve stopping aggravating exercise, cryotherapy, and early gentle activation (optimal loading).

- In the repair phase (0–45 days) the goal is to promote muscle repair and avoid injury aggravation. Treatment will involve controlled and progressive return to exercise and optimal loading including strengthening and gentle stretching. Attention should be paid to sensorimotor control, including the affected muscle and activation of synergistic muscles. Physical therapists are specifically qualified to advise on muscle recruitment and activation strategies as well as motor relearning strategies as part of a multidisciplinary team.[30] Return to activities often ranges from 1 week to 3 months, although mean recovery time for higher-grade tears in 1 study was reported to be 20 weeks.[3,26]

Treatment of fibrotic myopathy is well described and involves surgical correction by means of myotomy or tenotomy of the affected muscle.[29]

PREVENTION OF TRAUMATIC MUSCLE INJURY

As for treatment of intrinsic traumatic muscle injuries, prevention of these injuries in horses has also been largely translated from human athletes. However, even translating from one muscle and location to another in the same species is questionable due to variations in morphology, function, and properties,[3] so general principles are discussed. The importance of working in a veterinarian-physical therapist multidisciplinary team approach is emphasized, with physical therapists being specifically qualified to advise on stretching and warm-up for injury prevention strategies as part of a multidisciplinary team.[31,32]

Stretching and Injury Prevention

Stretching is generally recommended before exercise[2] to prevent muscle injury, but the evidence for stretching before exercise for injury prevention remains inconclusive.[3] Part of the reason for this may be the application of stretching for different muscles and activities may require different approaches, likely even more so in the horse. Using first principles, athletic activities can be broadly separated into high-intensity stretch shortening cycles (such as jumping, rapid acceleration) and low-intensity stretch shortening cycles (such as endurance riding or marching).[31] Activities reflecting high-intensity stretch shortening cycles are more likely to result in intrinsic muscle injury, and more likely to benefit from stretching. Controlled stretching creates a more compliant musculotendinous unit which is able to store and release a high amount of elastic energy and absorb the stresses and strains associated with the activity.[31,32] The use of discipline-specific stretching in horses as a training technique and pre-event warm-up technique is highly recommended.[32]

Warming up and Injury Prevention

Warming up is also generally recommended before exercise[2] to prevent muscle injury and improve aerobic performance, but the evidence for warming up to prevent injury in people is still inconclusive.[3] Similar principles apply for warming up as for stretching, with the aim being to increase the range of motion and compliance of the musculotendinous unit before exercise.[2] Although there has been research into warming up in horses, it has had a primary focus on improvements in cardiorespiratory function and not injury prevention.

Training for Fitness (Strength, Skill and Endurance) and Injury Prevention

The mainstay of management of athletic-induced muscle injury is ensuring the horse is fit enough for the exercise it is performing, and that appropriate rest days for the discipline and level of training are incorporated into the training program. This was shown in polo horses, where exercise-induced muscle damage was associated with playing early in the season, a period of rest preceding the exercise, and where the horse was considered not being fit enough for the level of play.[33]

The evidence for muscle strengthening to improve ability to resist injury is greatest for intrinsic muscle injury prevention in people.[3] However, there is little evidence in horses. Strength training involving combinations of sets and repetitions of isolated muscle groups are not applicable to horses, as it is not possible to instruct them to perform these.[32] However, working from first principles, understanding the anatomy and biomechanics of the muscle at risk could be valuable for targeting strengthening specific muscle groups during more global strength training such as the hamstrings (semimembranosus, semitendinosus, and gracilis muscles).[30] For example, use of graded inclines and uphill exercise using poles could be used for strengthening the hamstring hind limb muscles before more skills-based training is introduced. The latter might include turning on the hindquarters and would include development of proprioception, balance, and coordination for specific tasks and should be considered for the specific exercise the horse will be undertaking.

CLINICS CARE POINTS

- Intrinsic traumatic muscle injuries can be broadly divided into exercise-induced muscle damage including DOMS and muscle injury (muscle tears).
- Muscle has a remarkable ability to regenerate without fibrosis provided the basement membrane remains intact and satellite cells can migrate to fill in a deficit.
- Generalized intrinsic traumatic muscle injury, such as DOMS, can be suspected in horses presenting after unaccustomed exercise with elevated serum muscle enzyme activities (2 to 3 times baseline), mild generalized muscle soreness, and reduced performance.
- Overtraining and cumulative muscle damage can result in intrinsic exercise-induced muscle damage and remains an important differential diagnosis for unexplained elevations in muscle enzymes in horses.
- Focal intrinsic muscle injury can occur in horses ranging from grade I (rupture of a few fibers) to III (complete tear or rupture).
- Recovery is rapid with low-grade injuries, but high-grade injuries (grade III) resulting in loss of the basement membrane may lead to fibrous tissue instead of muscle regeneration, which may predispose to re-injury, noticeable defects, or contracture.
- Intrinsic muscle injury in Thoroughbred racehorses and barrel racers is most likely to involve the gluteus medius, gracilis, semimembranosus, and semitendinosus muscles.
- Muscle tears should be considered as possible causes of lameness in horses, and lameness evaluation should include palpation of all large muscle groups at a minimum. Diagnosis of muscle injury is currently best supported using ultrasonography, although gamma scintigraphy can also be used.
- Treatment and prevention are optimally performed with a veterinarian-physical therapist multidisciplinary team approach, as physical therapists are specifically qualified in rehabilitation program development including proprioception techniques for muscle recruitment and activation, motor relearning strategies, appropriate application of ice and compression, and stretching and warm-up protocols.
- Treatment strategies are usually aimed at reducing pain and restoring maximal function with protection, optimal loading, ice, and compression used rather than rest even for higher-grade injuries.
- Prevention strategies involve stretching, warming up, and appropriate strength and skill training for the discipline.

DISCLOSURES

The authors have nothing to disclose.

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Effect of a single-session osteopathic manipulation of dysfunctional caudal cervical vertebrae in non-lame sport horses

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A R T I C L E I N F O

Dataset link: Osteopathic single manipulation of the sacroiliac joint and lower cervical spine improves selected gait parameters in sport horses

Keywords:
Equine
Osteopathy
Manual therapy
Cervical dysfunction
Gait analysis
Decreased performance

A B S T R A C T

This study evaluated the effects of a single, one time off osteopathic manipulation on parameters of cervical osteopathic functional assessment and locomotion in non-lame sport horses with decreased performance due to cervico-vertebral dysfunction. Twenty-seven sport horses with caudal cervical dysfunction were randomly allocated to treatment (n = 19) or control (n = 8) groups. Osteopathic evaluation scoring and objective gait analysis using inertial measurement units were performed at walk, trot, and canter before and at 15 min, 3 days, and 15 days post-treatment. Results were analysed using generalised linear mixed models. Osteopathic manipulation significantly reduced the number of cervical osteopathic fixations (OF) in the treatment group compared to controls ($P < 0.001$). Cervical pain and muscle tone scores also decreased significantly in the treatment group compared to controls ($P < 0.01$). Gait analysis revealed improved protraction of the hindlimb on the most affected side (78 % of the horses) during straight-line trot and of the frontlimb during lunging toward the direction of the most affected side, with protraction values changing from (median and range) 28.24° (27.37–29.14) pre-treatment to 26.53° (25.64–27.45) at 3 days and 27.11° (26.34–27.86) at 15 days post-treatment ($P < 0.05$). There were no asymmetries consistent with lameness and no lameness scored by visual lameness assessment before nor after treatment. A single osteopathic cervical manipulation produced measurable improvements in both gait parameters and cervical osteopathic functional assessment scores (including ROM and presence of fixations), without causing further asymmetries, demonstrating therapeutic benefits for horses with caudal cervico-vertebral dysfunction. Further research with repeated treatments and long term benefits are warranted.

1. Introduction

The anatomy and biomechanics of the equine neck are complex, and its role is not only supporting the head, but contributing to maintaining posture and locomotion [1]. The neck is vulnerable to a range of pathologies that can cause pain and discomfort, thus, changing horses' movement patterns.

The relationship between poor performance in sport horses, abnormal locomotion and lower cervical dysfunction has been well stablished [2,3], for example, frontlimb lameness in horses has been sometimes associated with radiographic abnormalities of one or more cervical vertebrae [4] and with lower cervical radiculopathy [5]. The athletic demands of sport horses often result in pain in lower cervical vertebrae, the cervicothoracic junction, and related structures in middle aged, and even in younger horses [6] on which cervical pain is often overlooked. Exercise overload may also result in excessive muscular tension, which is described as a condition where muscles remain semi-contracted for a prolonged period, sometimes used as an indicator of acute stress in horses [6], resulting in neck stiffness, reducing range of motion and creating pain and loss of flexibility [7]. Similarly, pathologies such as cervical vertebral malformation and Wobbler Syndrome can cause arthritis of articular facets [8] and bursitis [9], similarly, vertebral misalignment and/or dynamic instability [11] may cause cervical spinal cord compression, neck pain and proprioceptive deficits leading to significant changes in locomotion and performance [2,3].

Early detection and treatment of neck disorders are essential to prevent further damage and dysfunction [10]. The importance of applying a more holistic approach to help prevent the occurrence of

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cervical pain and related injuries is paramount in horses in training and competition. In order to address these issues once present, various therapeutic approaches, together and/or besides conventional treatments can be used including physiotherapy and chiropractic and osteopathic approaches [11].

Somatic dysfunction from a vertebral segment is considered a central concept in the theory and practice of osteopathy. Somatic dysfunction can have different origins (e.g. articular, muscular or fascial) and different consequences at muscular, neuromuscular, fascial, visceral, neural, and even emotional level. Although the term is being reconsidered due to unclear pathophysiology and poor reliability of detection [12], other terms such as vertebral dysfunction, osteopathic dysfunction may be more straightforward and are more frequently used in veterinary medicine. As well as the colloquial terms "block" or "fixation", which refers to a localised mechanical restriction with respect to an adjacent vertebra. Vertebral dysfunction is a broader term that can be defined by altered muscle tone, tenderness, pain, loss of function or subtle changes in gait, which occur in the absence of pathological lesions and are related to abnormal function of the neuromuscular system [13]. The osteopathic assessment of cervical dysfunction is made through a meticulous manual physical examination. This examination encompasses a comprehensive evaluation of pain or tenderness, muscle tone, tissue texture, positional test, dynamic test (mobility and range of motion (ROM)) and the examination of the functional state of the nervous system and its relationship to somatic and visceral structures by evaluating cutaneous reflexes. The osteopathic evaluation involves ascertaining the most affected side and the ease or difficulty in rotation, flexion-extension, and lateroflexion (side-bending) of the affected joint segment. Some studies treating cervical and thoracic intervertebral joints using dynamic mobilisation exercises have shown successful results improving cervical flexion [14]. There are also positive effects of chiropractic [15] or osteopathic [16] manipulation on vertebral range of motion and on reducing pain in horses with back pain [17]. Colles et al. reports significant improvements in the degree of chronic frontlimb lameness after osteopathic treatment in a group of 51 horses with somatic dysfunction in the neck or back and no other diagnosed frontlimb pathology and no improvement with standard veterinary treatment [13]. However, there are very few reports of the effect of manual therapy on the equine neck region using chiropractic or osteopathic techniques [18,19]. In human medicine, there is a long-standing debate about the differences on the benefits of osteopathy versus chiropractic, which have a common origin and are relatively similar because both have similar principles: both are applied over bones, muscles, and connective tissue, using the hands to diagnose and treat abnormalities of musculoskeletal structure and function [20]. There are other terms that include manual techniques that were apparently very similar despite the efforts of certain groups to individualise them, such as manipulative therapy [20], forced-based manipulation [21] and spinal manipulation [22]. In comparative studies between different manual techniques, even with or without thrust, no important differences between the different techniques have been found [23].

Osteopathic treatment to alleviate mild discomfort in the horse's neck is a common practice in competition horses, often in the absence of documented pathology through diagnostic tests and imaging. In general, riders report good results from these treatments [24], with an improvement of horses' back flexibility, lateral bending, ease of collection and overall locomotion. Literature in humans support the use of osteopathy for treating vertebral dysfunction, muscle tension, reduced mobility and neck [25] and back pain [26,27], however, the mechanisms that result in these benefits remain yet to be fully understood [12,28]. To the knowledge of the authors, there are no studies on the effect of osteopathic treatment in the neck of horses.

The aim of this study was to determine whether a single, one time off osteopathic manipulation of dysfunctional caudal cervical vertebrae affects gait parameters, muscle tone, sensitivity/pain, osteopathic dysfunctions (i.e. presence of osteopathic fixations (OF) and therefore reduced ROM) and cutaneous reflexes in sport horses.

2. Material and methods

2.1. Study design

This was a randomised, controlled clinical trial with two groups: one receiving treatment, and the other serving as a control (Fig. 1).

2.2. Horses and inclusion/exclusion criteria

A total of 27 sport horses (14 geldings, 7 stallions, 6 mares), of three different breeds (17 Warmbloods, 6 Spanish horses, 4 Thoroughbreds) between 6 and 14 years of age (mean 9.4, median 9), from several riding centres in the same region, with suspicion of osteopathic cervical dysfunction of the caudal cervical area were evaluated and screened for the inclusion criteria described below, by one of the authors (MP), a veterinarian masked to the group assignment.

Inclusion Criteria:

- Active sport horses aged 6–14 years in a regular training program and usual competitions at medium-high level for the past 6–12 months, with a minimum of 3–5 days per week of directed work.
- Disciplines: dressage and show jumping.
- Rider complaint of discomfort during lateral bending, circling, and/or specific dressage exercises.
- Osteopathic dysfunction in the caudal cervical area (i.e. 1 or more OFs in 1 or more caudal cervical vertebrae. These OFs are single-sided because they do not normally present bilaterally in the caudal cervical region, as they may do in the atlanto-occipital joints). This criteria was evaluated by one of the authors (TR), an expert licensed equine physiotherapist and osteopath.

Exclusion Criteria:

- Musculoskeletal injury diagnosed or treated in the last 3 months and any invasive treatment or received medication in the last 3 months, such as intraarticular injection.
- Horses with clearly defective conformation of the back and/or limbs.
- Horses without rigorous monitoring of their work.
- Horses that experienced significant changes to their normal routine during the study period.
- Evidence of cervical joint arthrosis, fractures, or other injuries on radiographic or ultrasound imaging from their clinical history.
- Horses presenting lameness of > 1 out of 5 grades (linear 0–5 scale, where 0 is not lame and 5 is non-weightbearing).

As mentioned in the inclusion criteria, horses were screened and included in the study if they presented with caudal cervical dysfunction (s) (i.e. unilateral OF in any caudal cervical joint). During this initial evaluation, the direction of the OF (right or left rotation according to the position of the vertebral body) presented by the horses was determined by a functional assessment described below. At the initial evaluation, 21 of the 27 horses had caudal cervical fixations in the right side (78 %), therefore the right side was 'the most affected side', while only 6 horses had left side fixations (22 %). There were no cases with bilateral fixations. Gait analysis was performed comparing most affected versus less affected directions of the whole group regardless of their individual laterality.

The horses were then randomly allocated into an osteopathic treatment group (TG) ($n = 19$) and a control group (CG) ($n = 8$) after sample size calculation of each group.

2.3. Treatment

All horses received a full osteopathic examination [7,13]. The horses

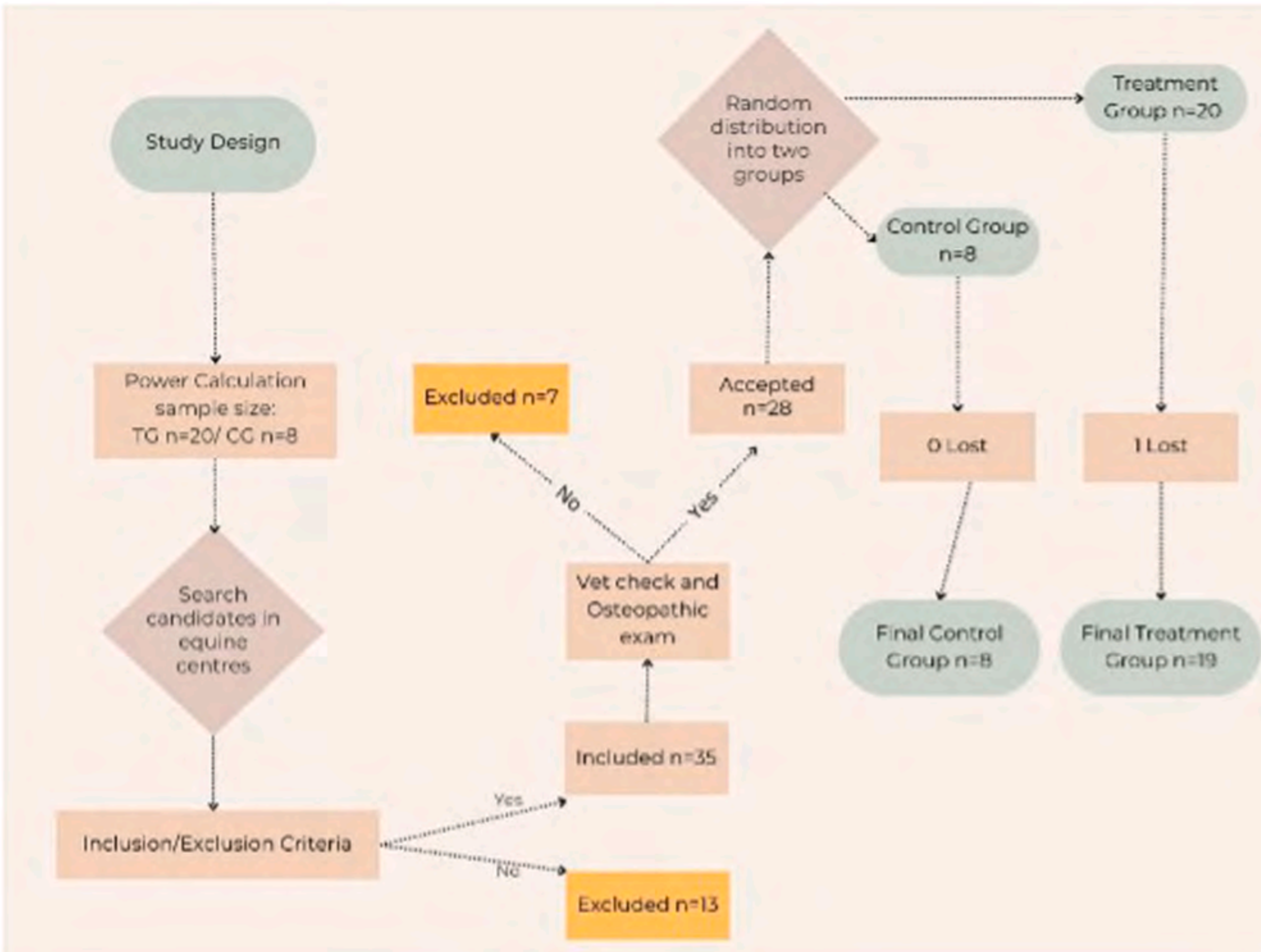

Fig. 1. Flowchart of horses' selection for the study.

in the TG received a single, one time off osteopathic manipulation (OM) using direct techniques (Fig. 2), described below, targeting only the lower cervical segments, while the control group received no treatment. The horses continued with their usual training and competition routines during the study, not being ridden until 24 h after the manipulation. The same expert licensed equine physiotherapist and osteopath who performed all the evaluations (for inclusion and before and after treatment), also delivered the manipulation to the treatment group, always utilising the same direct high-velocity, low-amplitude thrust technique to the lower cervical segments, consisting of a thrust on the transverse apophysis of the cervical vertebra just at the end-field point of cervical rotation at the fixation point, to induce a rotation while inducing a latero-flexion of the neck towards the ipsilateral side of the cervical dysfunction with the one hand (Video1). All evaluations and treatments were performed with the horses standing quietly in a familiar environment on a firm and even ground to minimise stress and variability.

Fig. 2. Osteopathic Manipulation of C6-C7 area: There is a fixation detected in the C7 segment with the right hand by contacting the dorsal part of the first phalanges on the ventral part of the transverse process of the C7 vertebra, taking a skin fold to stabilize the hold. The structure is put under tension until the barrier of motion is found with a slight cervical lateral flexion induced by the osteopath's left hand on the horse's neck. The thrust is performed with a high-speed, short-amplitude movement.

2.4. Evaluation

2.4.1. Osteopathic functional assessment

A complete osteopathic functional assessment was performed and recorded on day 1 (pre-treatment), day 3, and day 15 after treatment. This osteopathic functional assessment of the caudal cervical region included the examination of the following parameters: muscle tone, sensitivity/pain, osteopathic dysfunction score (i.e. mobility and ROM) and cutaneous reflexes. These parameters were evaluated and individually scored from 0 to 3 using a functional evaluation scale (Table 1), with slight modifications of the scoring proposed in previous studies [34–36]. It was not feasible to mask the horses belonging to each group to the person performing this assessment (TR).

Muscle tone and sensitivity/pain were assessed by applying manual light pressure between 5 and 10 cm beside the midline of the spinous processes. Vertebral dysfunction was determined by palpation and the finding of vertebral OF (e.g. signs of hypomobility) in the specific vertebral segment, sensitivity and/or tight joints) as reported in humans [29,30]. Cutaneous reflexes were evaluated in thoracic flexion and extension, lumbar extension, lumbosacral flexion and extension, and latero-flexion to both sides as reported in horses [31–33]).

Table 1
Functional evaluation scale for neck, back, and sacroiliac osteopathic functional assessment (modified from previous published studies [34–36]).

Clinical Parameter	Scoring			
	0	**1**	**2**	**3**
Muscle tone				
Manual evaluation of the muscle tone of the muscular groups in each area.	Soft musculature with no avoidance	Stiff musculature with no avoidance	Stiff musculature with avoidance characterised by lordosis or movement away pressure	Stiff musculature with avoidance characterised by kicking or biting
Pain				
5–10 cm off midline, abaxial to spinous process	No obvious avoidance	Avoidance and lordosis of spine or movement away from pressure	Avoidance plus tossing of head and/or tail swish	Violent avoidance characterised by kicking biting or jumping
Osteopathic dysfunction				
Manual osteopathic assessment of the spine (osteopathic fixations= OF)	No dysfunction (0 OF)	1 segment affected (1 OF)	2 segments affected (2OF)	3 or more segments affected (≥3 OF)
Cutaneous reflexes				
Manual reflex evaluation	Normal reflex	Decreased reflex with no clear pain (avoidance)	Clear pain (avoidance) or complete absence of reflex	Violent avoidance characterised by kicking biting or jumping

2.4.2. Lameness scoring

Videos for lameness scoring were recorded and objective gait analysis data was captured on day 1 (pre-treatment and 15 min post-treatment), day 3, and day 15 after treatment.

The lameness examination was performed by two double masked (to the group assignment and to the order of the videos), experienced veterinarians (one diplomate ECVS with over 15 years of experience, the other an equine surgeon with 9 years of experience in lameness examinations). The masked lameness examination was carried out by evaluating the video recordings performed of the horses moving at walk and trot in a straight line for 40 m, and in circles to the left and right on a soft surface (arena used for competition) at walk, trot and canter. Each limb of each horse was independently graded for lameness according to linear 0–5 scale (where 0 is not lame and 5 is non-weightbearing).

Horses were lunged in an arena familiar to them, at times of the day when they could be calm to avoid overexcitement and to work in a way as close as possible to the horse's usual routine. In straight line passes, the aid of a Global Positioning System ([a] Garmin Fenix V GPS) on the handler's wrist was used in order to maintain the same speed for each horse between measurements. At the lunge, the passes were performed by the same handler, maintaining the conditions as similar as possible in all passes.

2.4.3. Objective gait data collection

For the objective gait evaluation, 9 inertial measurement units (IMU's) (ProMove-mini, 200 Hz Equimoves system®)[b] were used. IMUs were placed lateral to the cannon bones of the 4 limbs, top of the head, withers, sacrum, right tuber-coxae and left tuber-coxae (Fig. 3). The

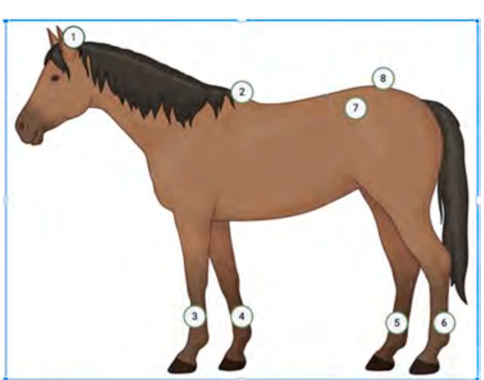

Fig. 3. Equimoves system®. Wireless inertial sensors for capturing motion data are attached to: 1. poll, 2. withers, 3–4. lateral side of the distal end of the 3th metacarpal bone, 5–6. lateral side of the distal end of the 3th metatarsal bone,7. left tuber-coxae, 8 tuber-sacrale, 9 (unseen) right tuber-coxae.

results were calculated using Equimoves, a validated system for equine gait analysis [37]. The following gait parameters were analysed: maximal protraction (MP) and maximal retraction (MR) of the limbs (left frontlimb (LF), right frontlimb (RF), left hindlimb (LH), right hindlimb (RH)), stride duration, stance duration, at walk and trot (in straight line and lunging to the left and right), and at canter (lunging to the left and right). Besides, to ensure the horses were not lame before nor after the treatment, upper body asymmetry was calculated using the same software: vertical displacement of the head minimum difference (HminDiff), head maximum difference (HmaxDiff), withers minimum difference (WminDiff), withers maximum difference (WmaxDiff), sacrum minimum difference (SminDiff), also known as pelvis (PminDiff), sacrum (pelvis) maximum difference (SmaxDiff), vertical head, withers and sacrum range of motion (ROM) at walk and trot. These parameters were not analysed at canter because it is an asymmetric air.

2.5. Statistical analysis

Data were analysed by one of the authors (JC) using the free statistical software JASP (c version 0.18.3), based on R (version 4.4.1). Generalised linear mixed models (GLMMs) were used to evaluate data from the osteopathic functional assessment, lameness scoring, and objective gait analysis.

Discrete numerical variables from the osteopathic functional assessment were modelled using a Poisson distribution with a log link function. In contrast, continuous variables from lameness scores and objective gait measurements were analysed using a Gaussian distribution with an identity link function.

For the osteopathic functional assessment, the fixed effects included time (three levels: before osteopathic manipulation [OM], 3 days after OM, and 15 days after OM), treatment group (TG vs. control group [CG]), anatomical region (neck, back, and sacroiliac), and their interactions. For lameness and objective gait data, fixed effects included time (four levels: before OM, 15 min after OM, 3 days after OM, and 15 days after OM), treatment group, and their interaction. In all models, horse ID was included as a random factor.

Each gait (walk, trot, and canter), performed in straight lines and on circles (toward the most affected and less affected sides), was analysed separately. When models showed significant effects, Bonferroni post-hoc tests were applied. A significance level of $p < 0.05$ was used.

Model validation included residual plot analysis to check normality and homoscedasticity for continuous data. For Poisson models, dispersion was assessed; in cases of overdispersion, negative binomial models were used. Model fit was compared using likelihood ratio tests and Akaike's Information Criterion (AIC).

Two additional fixed factors, laterality of the lesion (left vs. right) and equestrian centre (nine centres), were initially tested but later excluded due to lack of effect.

Sample size and power analyses were performed using GLIMMPSE software [38] Based on preliminary data from three horses per group, the estimated sample size needed to detect meaningful differences with a power (β) > 0.8 and significance level (α = 0.05) was eight horses per group.

To assess the potential influence of within-subject variability in gait symmetry as observed in lunging versus straight-line trotting, the standard deviation (SD) of four key parameters: Head, Withers, Sacrum vertical ROM, and MaxProtraction was calculated across all time points and horses.

3. Results

3.1. Osteopathic functional assessment

The outcomes of the osteopathic functional assessment overall demonstrated improvement in the treatment group compared to controls across all days of measurement, as depicted in Table 2. These showed that the muscle tone score of the cervical musculature resulted in a statistically significant reduction of tightness (muscle tone) in the treated group versus the control group ($p < 0.01$), with significant effects observed ($p < 0.001$) the interaction between day measurement and group factors ($p < 0.001$) (Fig. 4A). There were significant changes in the evaluation of neck pain on palpation ($p < 0.001$), where a decreased pain score was found. The statistical analysis revealed significant effects for the day measurement factor ($p < 0.001$) and the day measurement and group interaction ($p < 0.001$), while the group factor alone was not significant ($p = 0.722$) (Fig. 4B). In the evaluation of osteopathic dysfunction score, there were statistically significant reductions in the number of cervical osteopathic fixations, with significant effects for the day measurement and group interaction ($p < 0.001$) (Fig. 4C). No changes were observed in the back or sacroiliac area.

3.2. Lameness scoring

The majority of the horses included (>90 %) exhibited no (0/5) or minimal lameness ((0.5/5)). No statistically significant differences were observed in any of the limbs for any of the variables studied (time, group, and time-group interaction) across all gaits (walk, trot, and canter) in both, straight lines and circling before and after the treatment (Supp. Tables 1).

Table 2
P values obtained by generalised linear mixed models (GLMMs) for cervical Functional evaluation scale attending neck tone, neck pain and number of osteopathic fixations. df=degree of freedom. The level of significance was set at P ≤ 0.05.

Cervical neck tone evaluation		
Effect	**df**	**p**
Group	1	0.319
Day measurement	2	< .001
Day measurement ✻ Group	2	< .001

Cervical neck pain evaluation		
Effect	**df**	**p**
Day measurement	2	< .001
Group	1	0.722
Day measurement ✻ Group	2	< .001

Number of osteopathic fixations in cervical area		
Effect	**df**	**p**
Group	1	0.319
Day measurement	2	< .001
Day measurement ✻ Group	2	< .001

3.3. Objective gait analysis

Results revealed higher SDs for all parameters during lunging (Left and Right) compared to straight-line trotting. For instance, Head ROM SD was 17.5° and 17.8° in left and right lunge, respectively, compared to 12.9° in straight line. Similarly, Withers ROM SD increased from 10.9° (straight) to 14.7° (left) and 20.1° (right), and MaxProtraction RH SD rose from 1.5° (straight) to 1.99° (left). These results are consistent with previous findings [39], which reported greater between-measurement variation during circular exercise in sound horses.

3.4. Statistically significant changes found are reported below

3.4.1. Walk

When walking on straight line, MaxProtraction (in degrees) of the most affected hindlimb (MPRH) was significantly increased across days ($p < 0.001$) (Fig. 5A) (Supp. Tables 2). When walking in circles, the results differed significantly between most affected and less affected directions. On the less affected direction, only vertical head ROM was significantly increased across days ($p < 0.05$). In contrast, no significant differences were detected in any of the evaluated objective gait variables when walking in circles to the most affected direction. There was no effect of treatment on gait parameters at walk (Supp. Tables 3 & 4).

3.4.2. Trot

At trot in a straight line, MaxProtraction of the most affected hindlimb (MPRH) was significantly affected by both the time factor ($p < 0.001$) (Fig. 5B) and the interaction between group and time factors ($p < 0.05$) (Fig. 5C). Additionally, the MaxRetraction of the less affected hindlimb (MRLH) was significantly affected by the time factor ($p < 0.05$) (Fig. 5D). The stance duration of the left hindlimb was also affected by the time factor ($p < 0.05$) (Supp. Tables 5).

Trotting in circles revealed more pronounced differences between the groups. When trotting towards the less affected side, MaxProtraction of the less affected hindlimb (MPLH) and MaxRetraction of the less affected hindlimb (MRLH) were both significantly influenced by the group factor ($p < 0.001$ for both) (Fig. 6A & 6B) (Supp. Tables 6). Additionally, the vertical pelvic ROM was affected by the group factor ($p < 0.05$). When trotting in circles towards the most affected direction, MaxProtraction of the most affected frontlimb (MPRF) was significantly influenced by both the group factor ($p < 0.05$) (Fig. 6C) and the interaction between group and time factors, showing marked improvement in the treatment group compared to controls (Fig. 6D). The MaxProtraction and MaxRetraction of the most affected hindlimb (MPRH and MRRH) were significantly affected in the treatment group ($p \leq 0.001$ and $p < 0.05$, respectively). Similarly, the sacrum ROM was also affected by the group factor ($p < 0.05$) when trotting to the most affected direction (Supp. Tables 7).

3.4.3. Canter

The biomechanical analysis of cantering showed fewer significant changes compared to walking and trotting, with differences observed mainly on the less affected direction. When cantering to the less affected direction, the MaxProtraction of the most affected frontlimb (MPRF) was significantly affected by the group factor ($p < 0.05$) being higher in the treatment group. The stance duration of the left frontlimb and the MaxRetraction of the less affected frontlimb (MRLF) were both significantly affected by the time factor ($p < 0.05$). Additionally, the MaxProtraction of the left frontlimb showed a significant effect of the time factor ($p < 0.05$) (Supplementary Table 8) but not by the group factor. Cantering to the affected direction did not reveal any significant changes in the evaluated gait parameters (Supplementary Table 9).

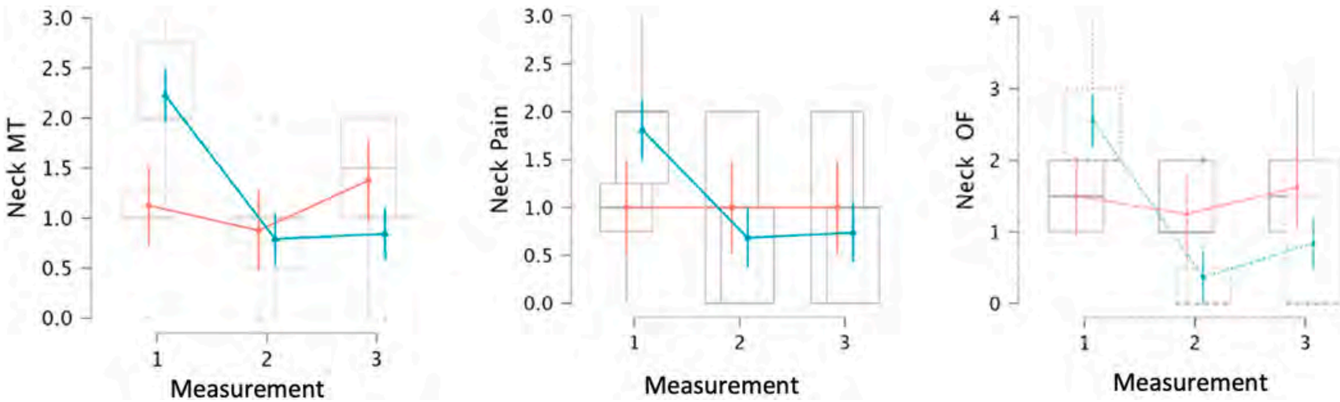

Fig. 4. Generalised linear mixed models Box plots indicating **A)** Neck Muscle Tone (MT) values according to treatment group ($p < 0.001$) and **B)** Neck pain values ($p < 0.001$) **C)** Number of neck articular osteopathic fixations (OF) ($p < 0.001$). Measurement: 1 = 15 min before Osteopathic Manipulation (OM); 2 = 3 days after OM; and 3 = 15 days after OM. Blue=Treatment group, Red=Control group.

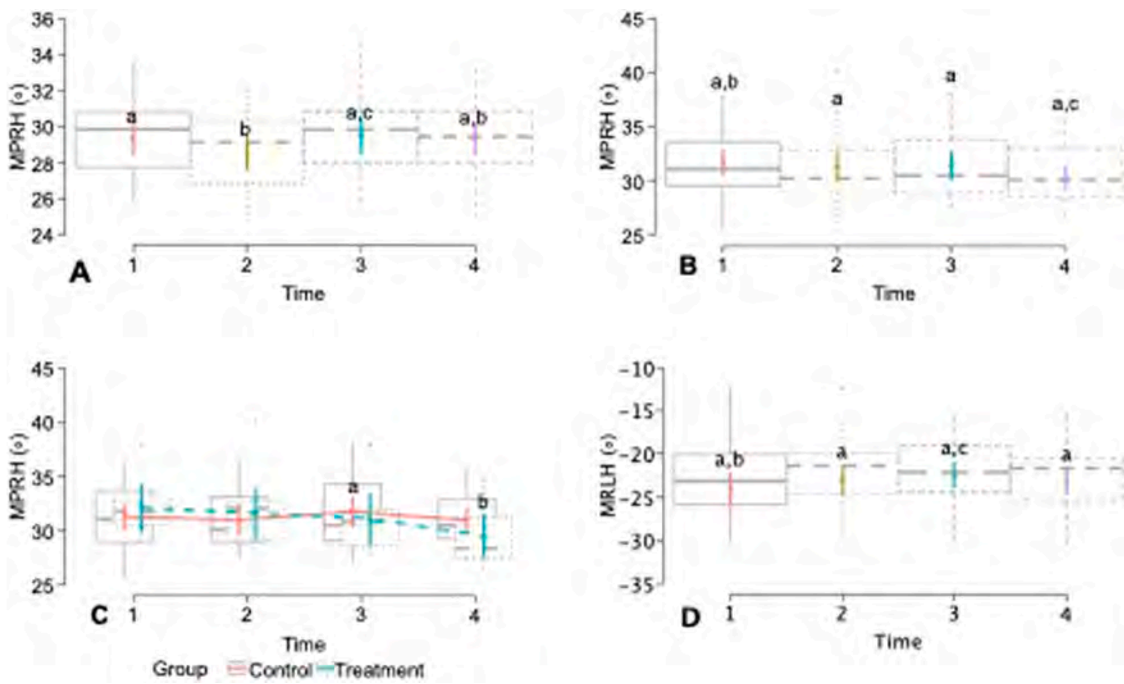

Fig. 5. Generalised linear mixed models Box plots indicating means (°) and their 95 % CIs for **A)** Max Protraction (MP) of the most affected hindlimb (RH) according to time factor at walking in straight line. **B)** MPRH according to time factor at trotting on straight line. **C)** MPRH according to treatment per time factors at trotting on straight line. **D)** Maximal retraction (MR) of less affected hindlimb (LH) values according to time factor at trotting on straight line. 1 = 15 min before osteopathic manipulation (OM), 2 = 15 min after OM, 3 = 3 days after OM, and 4 = 15 days after OM). $^{a\text{-}b\text{-}c}$= different low-case letters denote significant ($P < 0.01$) differences by the Bonferroni`s test.

4. Discussion

This study aimed to determine whether a single osteopathic treatment of dysfunctional caudal cervical vertebrae affects gait parameters, muscle tone, and pain in non-lame sport horses. It is important to emphasise that all horses included in this study were clinically sound, presenting with diminished performance attributable to cervical dysfunction but without clinical lameness, as confirmed by veterinary examination, objective gait analysis measuring upper body symmetries and minimal lameness scores. The results suggest that a single, one time off osteopathic manipulation of the caudal cervical spine in these sound sport horses with cervical dysfunction resulted in some significant, though slight changes in gait parameters and osteopathic variables, including reduction of pain and muscle tone.

Adaptive asymmetries are naturally occurring, non-pathological differences in movement or posture that develop over time as a horse adapts to its environment, workload, rider, or training. Some motion patterns may have a significant individual variation [40]. These adaptive asymmetries in sound horses, such as those seen in the horses in this study, are different to those resulting from frank lameness, which are pathological asymmetries caused by overt pain, injury, or dysfunction in the musculoskeletal or nervous systems, commonly originated in the lower limb but also in the proximal limb. These can be documented, for example, by measuring upper body asymmetries consistent with clinical lameness. There is a grey area when differentiating between pathological changes of the musculoskeletal structures able to cause pain, dysfunction and lameness and the subtle osteopathic findings, such as cervical vertebral fixations, causing no lameness but provoking diminished performance, often imperceptible to a clinical evaluation, but may be detectable to osteopathic (as well as chiropractic and

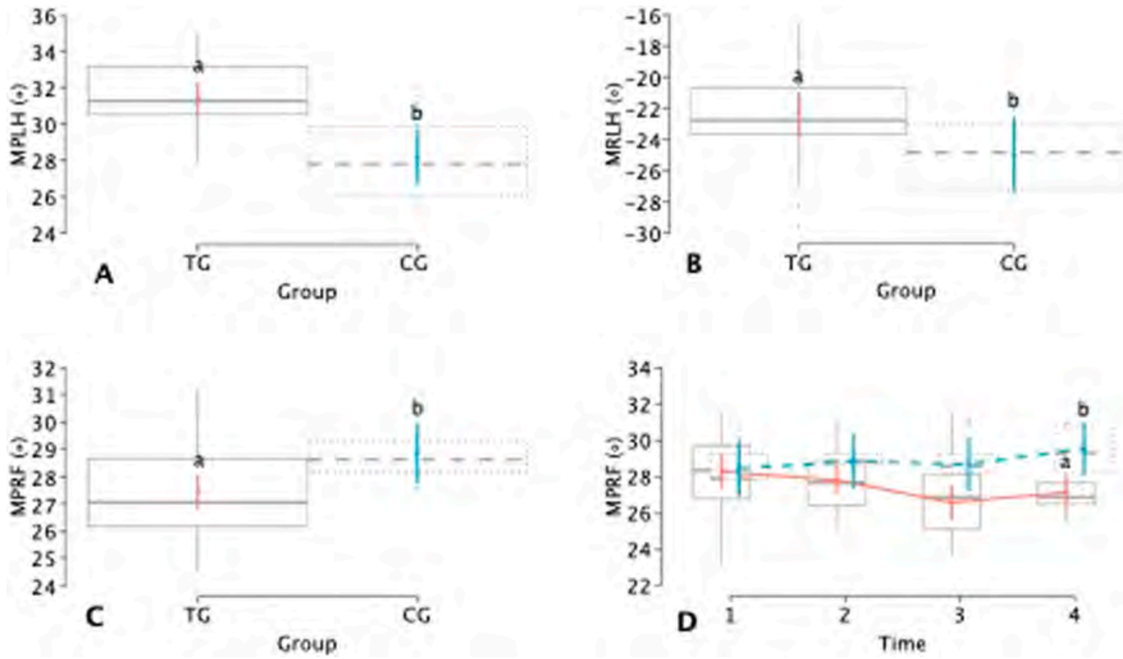

Fig. 6. Generalised linear mixed models Box plots indicating means (°) and their 95 % CIs for **A)** Maximum Protraction Less Affected Hind (MPLH) according to group factor at trotting in circles to the unaffected side. **B)** Maximum Retraction Less Affected Hind (MRLH) according to group factor at trotting in circles to the unaffected side. **C)** Maximum Protraction Most Affected Front (MPRF) according to group factor at trotting in circles on affected side. **D)** MPRF according to group x time factor at trotting in circles on affected side. 1 = 15 min before osteopathic manipulation (OM), 2 = 15 min after OM, 3 = 3 days after OM, and 4 = 15 days after OM). TG= treatment group, CG= control group. [a-b]= different low-case letters denote significant ($P < 0.01$) differences by the Bonferroni`s test.

physiotherapeutic) assessment.

The effects of the osteopathic manipulation performed in this study affected the various gaits studied differently. At the walk, minimal effects were seen. This suggests that an isolated cervical osteopathic manipulation may not have an impact on the biomechanics of walk. However, at the trot in a straight line and during lunging, max retraction and max protraction of the hindlimbs increased over time in the treatment group (a desirable effect) compared to the control group, although not always in both sides. This could be explained because all horses included were affected on one side only (i.e. unilateral caudal cervical fixations), this was the right side for the majority of the horses, which was named the 'most affected side' in this study. However, other factors must be considered in sound horses, such as laterality. While some studies suggest the presence of laterality in horses, the evidence remains limited [41]. In contrast, there is stronger and more consistent support for structural and functional asymmetries arising from well-established behavioural, nociceptive, and biomechanical mechanisms. Researchers caution against assuming that all observed asymmetries are due to inherent laterality. A major challenge lies in identifying which specific traits are most predictive of a horse's physical and mental health. Repetitive-use injuries, such as osteoarthritis, can lead to pain and altered mechano-reception, which may become the primary sources of left/right differences. Distinguishing true laterality, reflecting hemispheric specialisation, from asymmetries caused by injury or other physiological mechanisms remains difficult. Furthermore, most laterality studies have focused on presumably healthy horses, despite the fact that pain and tissue injury, both common in equine populations, can produce lateralised signs that may either obscure or amplify pre-existing lateralised functions. It remains unclear when acquired asymmetries override or interact with innate laterality mechanisms [42]

In our study, more differences could be seen while circling opposed to when moving on a straight line, however, with greater variability. These results are consistent with previous findings [43–45] which reported greater between-measurement variation during circular exercise in sound horses. In our study, horses were working on soft surface at the lunge, which has been shown to add variation when repeating across days compared to in straight line, but not as much as in hard surfaces, especially for head vertical movement. In our study, we also present measurements in the straight line, for comparison, and we compared horses against themselves (as well as against the controls) avoiding the between-horse variation. We did not do repetitions because, although according to the literature it reduces variability of the vertical movement upper body parameters [43], there is a warming-up effect of repeating that we wanted to avoid, because it would have changed the outcome of the treatment. The more differences seen in our study while circling suggests there is a positive effect of cervical osteopathic manipulation, especially on the frontlimb of the side the horses were circling towards to during lunging, suggesting improvement in flexibility and mobility. At the canter to the less affected direction, retraction and stance duration of the hindlimb of that side increased over time, suggesting improved weight-bearing and hindlimb ROM.

Overall, our results indicate that changes in the neck (i.e. joints and adjacent structures) due to the osteopathic treatment performed in this study seem to positively affect protraction and retraction of the hindlimbs. An improved or more natural neck positioning and therefore body posture, positively affects weight-bearing distribution [46] and protraction and retraction [47] in ridden and thoracolumbar kinematics in unridden horses [48]. Cervical mobility restrictions may produce compensatory effects on locomotor patterns throughout the horse's body. Extensive literature exists on the correlation between head and neck position and movement patterns in horses [48–50]. It can be argued that enhancing the mobility of the lower neck in horses with cervical dysfunction would be similar to those head and neck positions that permit greater freedom of movement. However, there is a lack of research on the impact of neck pathology on the biomechanics of locomotion [7,19], and even less on the effects of osteopathic treatment and other manual therapies of dysfunctional neck on horse's locomotion. Further research in this area is therefore warranted.

It is noteworthy that the majority of observed improvement in protraction and retraction of the frontlimbs, both during the trot and canter in circles, occurred in the inside limbs. It has been demonstrated that horses exhibiting lameness in a straight line, increase lameness and vertical head displacement on the painful inside limb when lunging [51]. While this finding pertains to pathologically lame horses and cannot be directly extrapolated to our clinically sound subjects, it provides methodological context for understanding the increased sensitivity of circular movement for detecting musculoskeletal irregularities. In our study, the enhanced detection of biomechanical improvements during lunging compared to straight-line movement suggests that circular exercise may similarly reveal functional changes in sound horses with cervical dysfunction, albeit through different mechanisms than those observed in lame horses. Research in human shows that axial loading of the cervical vertebrae is increased by latero-flexion, which can affect cervical motor control [52] and potentially increase nerve root compression [53], and subsequently may affect the movement of the inner limb even further when circling. While direct extrapolation from human to equine cervical biomechanics requires caution, this research provides theoretical context for understanding how cervical dysfunction might differentially affect limb function during circular movement. The application of these principles to our clinically sound horses with cervical dysfunction suggests that the restoration of normal cervical mobility through osteopathic manipulation may alleviate functional restrictions in horses with cervical dysfunction.

Although equestrians often seek chiropractic and osteopathic interventions with successful outcomes when reporting resistance issues in one rein (i.e. circling), scientific evidence supporting this improvement after using osteopathy was previously unavailable. This study provides some novel insights into the biomechanical implications of osteopathic manipulation of the neck in clinically sound horses with functional cervical restrictions, such as increasing protraction of the frontlimb, particularly during circular movement, which may explain the anecdotal improvements reported by riders.

No differences were observed in upper body vertical motion symmetry (head, withers and sacrum), which is a commonly used parameter to aid with diagnosing lameness or limb motion irregularities [54,55]. It is therefore not surprising that there was no significant difference either in the lameness scores recorded by two masked veterinarians and in the upper body vertical asymmetry. As the level of lameness in the horses at the start of the study was non-existent to minimal, it was expected that no major changes would be observed. More importantly, no detrimental changes on motion pattern symmetry were caused by the treatment.

The small but significant and clinically relevant biomechanical changes observed in this study were as anticipated, as anecdotal evidence from riders and veterinary health professionals indicates that such improvements post-treatment are subtle. However, apart from being subtle, the changes were not consistent in both sides or for all gaits. This is due to several reasons. Firstly, cervical dysfunction was often unilateral and the participating horses were naturally affected by neck dysfunction, where natural variability is expected, in contrast to experimental studies where most factors can be controlled. Secondly, the horses were assessed overground and not on a treadmill as in previous studies with similar objectives [56] Thirdly, only one treatment was performed and not repeated as it is usually done in these type of treatments to ensure a more obvious and long lasting effect [17,57]. Finally, the horses at baseline had only subtle cervical dysfunction, consequently, leading to only subtle changes after treatment, which may be missed by the measuring systems and the statistical analysis.

In spite of the subtle biomechanic changes found mentioned above, the osteopathic functional assessment revealed notable changes, including a decrease in muscle tone and a reduction in palpation-induced pain. Pain and increased muscle tone are two of the typical signs of cervical dysfunction, along with decreased performance, unwillingness to work with the bit, subtle hindlimb gait abnormalities, lack of drive and possibly frontlimb lameness [19]. It has also been associated with atrophy in the cervical muscles [18], a pathological condition that may be caused not so much by a tissue pathology but rather by a neuromuscular problem and therefore susceptible to improvement through cervical manipulation [13]. Therefore, improving pain, reducing muscle tension, and increasing limb protraction and retraction is desired when treating cervical dysfunction. These findings align with other equine osteopathic study where biomechanical assessments proved inconclusive, yet semi-objective and subjective measures such as physical examinations, lameness evaluations, and pressure algometry yielded significant results [58]. This discrepancy underscores the pressing need to develop and implement alternative objective methodologies for assessing the efficacy of osteopathic manipulations and other manual therapies for the rehabilitation of equine subjects. While biomechanical considerations remain relevant, their limitations in this context suggest that a more comprehensive approach is necessary. In human osteopathic research, there has been a shift towards employing the neuromotor model to evaluate the efficacy and elucidate the mechanisms of action of osteopathic manipulations [59,60]. This paradigm shift from a purely biomechanical model to a more integrative approach could provide valuable insights if adapted for equine osteopathy. Future research should focus on developing and validating such multifaceted assessment tools that can capture the complex effects of osteopathic interventions in horses, potentially combining biomechanical, neuromotor, and physiological parameters.

This study acknowledges several inherent constraints common to manual therapy research. A primary challenge in the field is the lack of standardised approaches in interventions, often leading to variations in treatment techniques and protocols [61]. Additionally, manual therapy studies frequently face issues with sample size, difficulties in blinding, insufficient understanding of mechanisms of action [62], and barriers to integrating research evidence into practice [63]. To address these limitations, a rigorous methodology was implemented in this study. A power calculation was conducted to determine an appropriate sample size on each group, and pre- and in-study tests were standardised using a functional evaluation scale, although one of the main limitations of the study was that it was not possible to mask the assessor of the osteopathic functional assessment to the group assignment. Due to the nature of the osteopathic evaluation and treatment, the practitioner had to be aware of the horse's clinical presentation in order to perform a meaningful manual assessment and apply appropriate techniques. Blinding the practitioner to the horse's condition was not feasible within this context, as osteopathic evaluation is inherently responsive to perceived dysfunctions, therefore if the practitioner would have been blinded (osteopathic evaluation made by another person), this practitioner would have made the diagnosis of the problem anyway when treating (because in osteopathy, and other manual techniques, the evaluation and therapy blend within the manipulation itself). While the osteopathic functional evaluation may be subjective, we used a semi-quantitative, a pre-defined scoring system designed to reduce personal interpretation and increase consistency across horses and time points. The same practitioner applied this scale throughout, limiting inter-rater variability, which could be a downside of having multiple practitioners.

To further mitigate bias, the two independent veterinarians assessing lameness were masked to the horse's clinical status and group allocation. Besides, inertial measurement units were employed for objective gait analysis in order to verify that no upper body asymmetries consistent with lameness were provoked with the osteopathic treatment, or at least no adaptive asymmetries of the head and trunk resulted from the treatment in these sound horses. Objective gait analysis also aimed to document improvement of protraction and retraction of the limbs, which is a positive biomechanical adaptation to the release of the osteopathic fixation of the caudal neck, particularly increased ROM of the frontlimbs.

In addition, a single manipulation technique was used to avoid compensations or cumulative effects that might arise from manipulating multiple structures simultaneously, as it is common in clinical practice. While the use of horses in active competition enhances the study's ecological validity and clinical relevance, it potentially increased intrinsic variability, particularly in the control group. This approach, however, aligns with the aim to bridge the gap between research and clinical practice, albeit at the cost of some experimental control. Moreover, by employing this methodology in a real-world setting, this study contributes to a better understanding of the mechanisms of action underlying osteopathic manipulations, addressing one of the fundamental limitations in the field.

5. Conclusion

The positive changes observed in muscle tone, cervical pain, protraction and retraction of the limbs in this study, particularly on the same side towards which the horses were trotting or cantering to, supports that osteopathic manipulation of lower cervical vertebrae presenting cervical dysfunction can provide slight but positive effects in non-lame sport horses with mild decreased performance due to caudal cervical dysfunctions. Further research is needed assessing horses with more severe clinical signs, evaluating the effects of multiple manipulations and the inclusion of longer follow-up periods.

Authorship

The study was designed by Toni Ramon, Dr. Marta Prades, and Dr. Constanza B. Gómez Álvarez, who also contributed to the writing, and interpretation of data. Dr. Jorge U Carmona was responsible for the statistical analysis and data analysis. Dr. Marta Prades conducted the initial physical examination and assessment of inclusion/exclusion criteria for the horses. Toni Ramon performed the osteopathic functional assessment and manipulations.

CRediT authorship contribution statement

Toni Ramon Boixaderas: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Constanza B. Gómez Álvarez:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Jorge U Carmona:** Methodology, Formal analysis. **Marta Prades:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Ethical animal research

This clinical trial did not imply pain, suffering or further morbidity of the studied animals, therefore, this type of non-invasive animal study does not require a specific authorisation by an ethical committee for animal experimentation.

Sources of funding

This research did not receive any funding. The Equimoves equipment was provided by SLU, Uppsala, Sweden.

Owner informed consent

Owners gave consent for their horse's inclusion in the study, they were informed about the nature of the clinical trial and signed an informed consent accordingly.

Manufacturers' addresses

[a] Garmin International Inc. Olathe (Kansas, USA)

[b] Equimoves System (EquiMoves®-www.equimoves.nl) consisting of nine ProMove-mini IMUs (Inertia Technology B.V., Enschede, The Netherlands.

[c] JASP (JASP 0.18.3 (Intel), University of Amsterdam, The Netherlands) - R-Studio, Boston, Massachusetts, USA. and SPSS 24.0 (IBM, USA).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.eqre.2025.100037.

Data availability

Osteopathic single manipulation of the sacroiliac joint and lower cervical spine improves selected gait parameters in sport horses (CORA)

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THE HORSE
YOUR GUIDE TO EQUINE HEALTH CARE

Preventing Tendon Injury and Reinjury in Horses

June 18 2025 ed by Christa Lesté-Lasserre, MA

Here are 10 ways to reduce your horse's risk of sustaining tendon damage or injury.

Topics: Article, Injuries & Lameness, Lameness, Ligament & Tendon Injuries, Ligament & Tendon Injuries, Sports Medicine

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10 ways to reduce the risk of damaging these dynamic structures

Tendons in horses' legs help make them capable of phenomenal athletic efforts. | iStock

Tendons connect muscle to bone via their tough, fibrous strands. Wherever animals have bones and muscles, they have these collagen-fiber structures. But tendons in horses' legs are unique in that they store high levels of quick energy, which they release after each step, making them capable of phenomenal athletic efforts.

It’s a “brilliant” design that’s helped this rapid-reaction prey species outrun many of its predators across its evolutionary history, says Claire O’Brien, MRes, PgDip, BSc (Hons), FHEA, of the University of Limerick, in Ireland, previously a researcher at Aberystwyth University, in the U.K.

But the tradeoff for such a design is these weight-bearing tendons are especially prone to injury and reinjury, says Roger Smith, MA, VetMB, PhD, DEO, Dipl. ECVSMR, ECVS, FRCVS, professor of equine orthopedics at the U.K.’s Royal Veterinary College Hawkshead Campus, in Hatfield.

Both the deep digital flexor tendon (DDFT) and especially the superficial digital flexor tendon (SDFT) are at risk for damage, meaning months or years of time off work or even the end of a horse’s athletic career.

Ideally, we’d reduce horses’ risk of sustaining tendon damage altogether, our sources say. Here are 10 ways to help.

1. Understand biomechanics and “biothermics” of tendon function.

Tendons are viscoelastic structures, meaning they stretch, and their mechanical behavior changes depending on how far and frequently they’re stretched, Smith says. Basically, tendons efficiently provide energy when weight-bearing but break down when stretched beyond their limits.

The SDFT, for example, stretches up to 16% in high-impact situations such as jumping and galloping, Smith says.

O'Brien adds, "If you could just watch a video of a horse coming to a fence in slow-motion and see that last step before takeoff, you'd be absolutely shocked to see how much the distal limb drops down."

A stretch extending beyond that 16%, however, can damage the fibers, says Smith. Even so, that's not the most common cause of injury. More often, he says, tendons get repeatedly loaded to the point of heating up. Researchers estimate core SDFT temperatures reach 110 F (43.5 C) during high-
intensity training sessions, O'Brien says.

That's certainly not what you want, since scientists have shown that tendon cells—known as tenocytes—incur microscopic levels of heat damage starting at 108.5 F (42.5 C). Over time repetitive microdamage builds up, causing injury and lameness.

In fact, it's the microdamage—not traumatic accidents—that's the leading cause of tendon injury and reinjury, O'Brien says.

Knowing this is an important first step in safeguarding tendons, our sources say.

2. Know the Risk Factors When Selecting Your Athlete.

Armed with that knowledge, buyers and breeders can make informed decisions when purchasing horses because good selection is a critical part of injury prevention, Smith says.

Genetics play a role in tendon quality, and researchers have even identified tendon-injury-related genes in both humans and horses, he says. Yet, while genetic information can be helpful, it's not essential, "as the more dominant risk factors are those that the horse experiences during its career."

The greatest risk factor is prior tendon injury, says Smith. In the case of a prepurchase exam, veterinarians should palpate for signs of previous lesions. Ultrasound can also be helpful because healed injuries are not always detectable otherwise. Old tendon injuries reveal a tendency for tendon problems, and the horse is more likely to re-injure compromised tissues.

Importantly, this does not mean people should not buy horses with these risk factors, Smith says. Rather, they should be aware of the increased risks and prepared to be more vigilant or select a lower-intensity discipline that reduces chances for tendon injury.

3. Feel, watch, and monitor tendons regularly.

Early injury in some tendons—especially the SDFT, which extends along the back of the horse's leg from the carpus (knee) to the pastern—can be visible, says Christopher Elliott, BVSc (hons), MANZCVS, Dipl. ACVSMR, of Palm Beach Equine Clinic, in Wellington, Florida.

So, it's up to us to "dot the I's and cross the T's with paying attention to any change within that tendon," he explains. "You should know what your horse's leg feels like every day in terms of size, shape, contour, and temperature in all four limbs." Ultrasound exams—whether regularly in healed tendons or after detecting a potential issue, can also provide critical feedback about how the tendon is coping with training, he adds.

Smith recommends visual inspections, palpation, and even Doppler ultrasound (which measures blood flow and can pick up subtle signs the eye can't) checks after every high-intensity workout in previously injured regions and in areas of concern. "This is currently one of the best strategies for prevention," he explains. While an injury can't be avoided altogether, detecting damage as early as possible and starting treatment can prevent further damage.

4. Use Boots Wisely.

Well-placed and well-fitted boots can help protect tendons and other structures from rare traumatic injuries that could happen when the horse clips himself or hits a jump, which some horses are particularly prone to doing, O'Brien says.

Nevertheless, these acute injuries are relatively uncommon compared to the risks of repetitive microdamage caused by overheating. "We continue to use boots on the horse, knowing they can increase tendon temperature even further during sessions," she says.

If riders prefer using boots to protect the legs from acute trauma, they should apply them shortly before intense exercise and remove them immediately afterward, she says.

Simply airing the legs should help tissue temperatures drop, notes Smith. But cryotherapy—ice packs, cold hosing, or commercial ice boots—is also particularly effective.

Ensure boots are as ventilated as possible and/or made of materials that do not generate heat, O'Brien adds.

"Riders should check that any companies promoting such features in their products are transparent about any unbiased research to support their claims," she says.

5. Use evidence-based training.

Progressive training programs based on scientific evidence contribute to core and muscle strength while preventing overwork-related fatigue, Elliott explains: “We know that too much exercise or inappropriate exercise increases risk factors for orthopedic injury, particularly in the soft tissues.”

Horse owners must also allow appropriate recovery time between training sessions, especially before advancing to more strenuous exercise, O’Brien adds. “Tendons need the chance to recover between the cyclical bouts and to have enough variety in the training and surfaces to allow time to recover in between sessions that tend to induce greater strain, like show jumping, galloping, and any kind of high-intensity work,” she says.

Furthermore, to limit repetitive movement that can strain the same tissues repeatedly, Elliott also recommends cross-training in different disciplines and on a variety of footing.

“Statistics have shown that the majority of tendon injuries occur during the training program, not during competitions,” O’Brien says. “It’s a difficult balancing act, but just make sure your program is as evidence-based, varied, and appropriate as possible.”

Warming up might or might not benefit horses’ weight-bearing tendons, because—unlike humans—they spend so much time standing, says Smith. More research into warmup’s effects on tendon health is needed, he adds, but it remains essential for general musculoskeletal health, especially the joints.

Meanwhile, breeders and trainers should follow evidence-based conditioning programs that help young horses’ tendons adapt to athletic work, Smith adds. “You’ve got to encourage animals to exercise in a controlled fashion when they're young, while those tendons are still adaptable—which is when they're growing," he says.

6. Recognize Your Horse's Fitness.

Tendons don't work individually. Therefore, our sources say it's important to maintain a "whole horse" view of the animal when managing tendon health.

Owners must recognize the overall health and fitness of their horses "to ensure that the legs are as orthopedically comfortable as they can be," Elliott says.

O'Brien and Smith agree. "We need to be objectively monitoring the training we're making horses undergo," says O'Brien, whether that's tracking our distance, gaits, speed, and other stats with an equestrian smartphone app, or going higher tech, under veterinary supervision, with heart rate and other monitors.

7. Notice Hoof Shapes and Angles.

The horse's hoof angle could make a significant difference in tendon strain, says Elliott. "You need well-balanced, well-maintained feet that have a nice, short breakover and are appropriate to the specific sports discipline," he says. (Experts define breakover as the moment the heels leave the ground and begin to rotate over the toe.)

Critically, people need to understand how bar shoes, wedges, or anything that elevates the heel could affect various tendons, says Aimee Colbath, VMD, MS, DACVS-LA, assistant professor in the section of large animal surgery at Cornell University College of Veterinary Medicine, in Ithaca, New York.

Heel elevation reduces strain on the DDFT, which can create more strain on the SDFT. “This is a common misconception, and it’s a bit counterintuitive,” she says.

Still, it makes anatomical sense, she adds. The DDFT attaches to the third phalanx, or coffin bone, but the SDFT attaches at the upper portion of the second phalanx, or short pastern bone. “By raising that foot up, you’re … raising the thing that the DDFT attaches to,” she says. “That’s not true for the SDFT.”

Smith says we need more scientific evidence linking injury risk and specific shoeing techniques. Depending on the horse’s conformation, there is a lot that can be done with such techniques to help him.

8. Think Smart About Footing.

Footing science is complex; even researchers don’t always agree on what’s best. In part, that’s because surfaces affect different tendons in a variety of ways.

For example, deeper, softer, more “sinkable” ground might contribute to higher strains on the SDFT, says Colbath. But other scientists studying racehorse injury risk suggest the opposite. In the latter situation this is thought to be because softer ground slows racehorses, which reduces peak tendon loading. In other disciplines, with lower maximal speeds, we might not see the same effect.

> “Avoid uneven surfaces, poorly maintained surfaces, or surfaces that are either too hard or too soft.”

As a rule, owners should seek out consistent footing. “Avoid uneven surfaces, poorly maintained surfaces, or surfaces that are either too hard or too soft,” Elliott says.

Dr. Christopher Elliot

9. Believe in Time Off.

Researchers have shown that tendons such as the SDFT undergo significant structural changes after intense workouts—with maximal changes at 48 hours. “The tendon is really doing a lot of hard work trying to repair any of the minor damage that occurred,” O’Brien explains.

When SDFTs have 72 hours to recover, they appear as they did prior to the workout on ultrasound imaging. This suggests good, strong repair, she says.

By contrast, a lack of sufficient recovery time could lead to even more microdamage. “So, if you were to, say, gallop the horse on a Monday and then do show jumping on Wednesday, research would lead you to believe that you may be more likely to cause a significant rupture of that tendon than if you’d let it rest for three days,” she says.

Meanwhile, owners of horses recovering from tendon injuries must respect and follow the rest and rehab programs their vets provide, Elliott adds. These can last months and follow a slowly progressive return to exercise, which allows the tendon to fully heal.

10. Support and Follow Ongoing Tendon Research

Many scientists worldwide are studying how to protect horses' tendons from and treat injuries. Several studies are already underway—such as investigating genetics, risk factors, the influence of footing and shoeing, and biomarkers of early pre-lesion changes. These all could offer important insight into how we manage our athletes for optimal tendon health.

Smith's team, for example, is currently developing molecular inhibitors designed to stop the progression of tendon degeneration while it's still at a microscopic phase. This approach could address damage before anyone even notices it or it escalates to injury.

Individuals interested in supporting research can donate to their favorite vet school or charity that supports equine research.

Take-Home Message

Tendon injuries might be a common curse among sport horses, but that doesn't mean they have to be. With foresight and a strong, evidence-based preventive strategy in place, owners and riders can reduce the risks of their horses sustaining damage to these dynamic structures.

Christa Lesté-Lasserre, MA

Passionate about horses and science from the time she was riding her first Shetland Pony in Texas, Christa Lesté-Lasserre writes about scientific research that contributes to a better understanding of all equids. After undergrad studies in science, journalism, and literature, she received a master's degree in creative writing. Now based in France, she aims to present the most fascinating aspect of equine science: the story it creates. Follow Lesté-Lasserre on Twitter @christalestelas.

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Posture and postural dysfunction in dogs: Implications for veterinary physiotherapy

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Posture and postural dysfunction in dogs: Implications for veterinary physiotherapy

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ABSTRACT

Postural assessment is an important part of the veterinary evaluation of a dog's neuromusculoskeletal function. It forms an important part of the clinical examination by physiotherapists and specialists in veterinary rehabilitation and sports medicine and is well researched in humans, which has allowed treatment approaches to be developed and validated. This narrative review aims to complement the veterinary literature, which largely quantifies the impact of various conditions on posture, by synthesising the physiotherapy literature, to help translate the use of postural assessment as a basis for the development and validation of treatment techniques to improve outcomes in dogs.

Introduction

Posture

Postural assessment is an important part of the neuromusculoskeletal function component of physiotherapy and veterinary assessment (Kendall et al., 1993; Petty and Moore, 1998; Janda et al., 2007; Dingenen et al., 2018). Posture is the biomechanical alignment of the body and its orientation within and in relation to the environment (Shumway-Cook and Woollacott, 2007). Posture is understood as the relationship of the segmental regions of the body to each other (Kendall et al., 1977). Posture related terminology, used within the concept of posture, is presented in Table 1.

Factors that can affect posture

Postural control has been shown to decline in aging dogs (Vero et al., 2021) and humans (Du Pasquier et al., 2003). Centre of Pressure has been used to measure balance and recovery outcomes in humans with anterior cruciate ligament insufficiency (Zätterström et al., 1994) and in dogs with cranial cruciate ligament disease (Carrillo et al., 2018). The general posture of an animal can indicate factors such as pain or weakness and can be perpetuated by inadequate neuromotor control (Morton and Griffiths, 1985; Frank, 1999; Stasiak et al., 2003; Platt & Garosi, 2004). Emotional factors can affect dogs' presenting postures (Mota-Rojas et al., 2021; Ferres et al., 2022) and therefore complicate postural assessment. However, the same emotional factors affect people's presenting postures (Petty and Moore, 1998).

Physiotherapy aims

Physiotherapy in all species includes a focus on restoring appropriate movement patterns (Comerford and Mottram, 2001; Janda et al., 2007; Hodges et al., 2013; McGowan and Hyytiäinen, 2017; Sahrmann et al., 2017) which often includes correction of postural dysfunction so that muscles can be recruited functionally (Kendall et al., 1977; McGowan and Hyytiäinen, 2017). During restoration of muscle function and control, principles of motor (muscle) re-learning and retraining are used (Shumway-Cook and Woollacott, 2007; Hodges et al., 2013). To apply these techniques effectively, movements should be as "normal" as possible, including restoration of the baseline posture (alignment) (Kendall et al., 1977; Petty and Moore,1998; Shumway-Cook and Woollacott, 2007).

Clinical reasoning in a dog with Hip Dysplasia

The atrophied pelvic limb muscles in a dog with hip dysplasia (HD) (Farrell et al., 2007) could result in a postural dysfunction that involves

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Table 1
Definitions of terminology related to posture (Panjabi, 1992; Soderberg, 1997; Shumway-Cook and Woollacott, 2007).

Term / concept	Abbreviation	Description
Centre of Mass	COM	Point at the centre of the total body mass
Centre of Pressure	COP	Centre of the distribution of the total force on the supporting surface
Centre of Gravity	COG	Vertical projection of the COM
Base of support	BOS	Area of the body in contact with the supporting surface
Postural stability (balance)		Component of postural control that relates to the ability to control the COM within the BOS
Neutral zone		Physiological movement control of a joint position that relies on active stabilisation of by the surrounding muscles to prevent injury
Postural tone		Muscle activity required to counteract the force of gravity

excessive thoracolumbar flexion, caudal pelvic tilt, and a shift of the dog's COM cranially to compensate for the pelvic limb weakness, leading to overactive thoracic sling muscles. In physiotherapy, the ability to achieve and sustain normal alignment while the limb weakness is challenged would signify appropriate postural control (Shumway-Cook and Woollacott, 2007). Physiotherapy intervention would, therefore, aim to increase limb muscle activation and control, whilst concurrently decreasing overactivity in the muscles that are causing compensatory abnormal posture (Comerford and Mottram, 2001; Janda et al., 2007; Sahrmann et al., 2017). Thus, in the example of the hip dysplastic dog described, physiotherapy would include facilitation of normal pelvic limb posture and maintenance of this under challenge, whilst simultaneously de-recruiting iliopsoas and other muscles that are contributing to the flexed spinal posture.

This narrative review aims to complement the veterinary literature, which largely quantifies the impact of various conditions on posture, by synthesising the physiotherapy literature, to help translate the use of postural assessment as a basis for the development and validation of treatment techniques to improve outcomes in dogs.

Posture

Posture is the biomechanical alignment of the segmental regions of the body in relation to each other, and the environment (Kendall et al., 1977; Shumway-Cook and Woolacott, 2007). The optimal alignment of these segmental regions allows the body's equilibrium to be maintained against gravity with the least expenditure of energy (Shumway-Cook and Woollacott, 2007). Although bipedal 'ideal alignment' is different from that of a quadruped, the human derived concept of equilibrium and minimising energy expenditure is applicable to dogs.

Ideal posture is assessed from different aspects of a human patient and in relation to the vertical line of gravity (Kendall et al., 1977; Petty and Moore, 1998; Shumway-Cook and Woollacott, 2007). For the static standing posture of a human, an ideal alignment from the lateral view would create a 'plumbline' from the ear, through the shoulder joint, midway between the back and abdomen, through the greater trochanter, over the knee and down to the lateral malleolus (Kendall et al., 1977; Petty and Moore, 1998; Shumway-Cook and Woollacott, 2007; Fig. 1.a.). From the anterior and posterior views, a line down the midline of the body should reveal trunk and limb symmetry (Kendall et al., 1977; Petty and Moore,1998; Fig. 1.b.).

For dogs, diagrams are available for specific breeds (Kennel Club, 1989) and current standards (Fischer and Lilje, 2011) but these are not based on scientific assessment of the energy-efficiency of maintaining such postures.

Postural control

Body alignment (posture), muscle tone and postural tone are all part

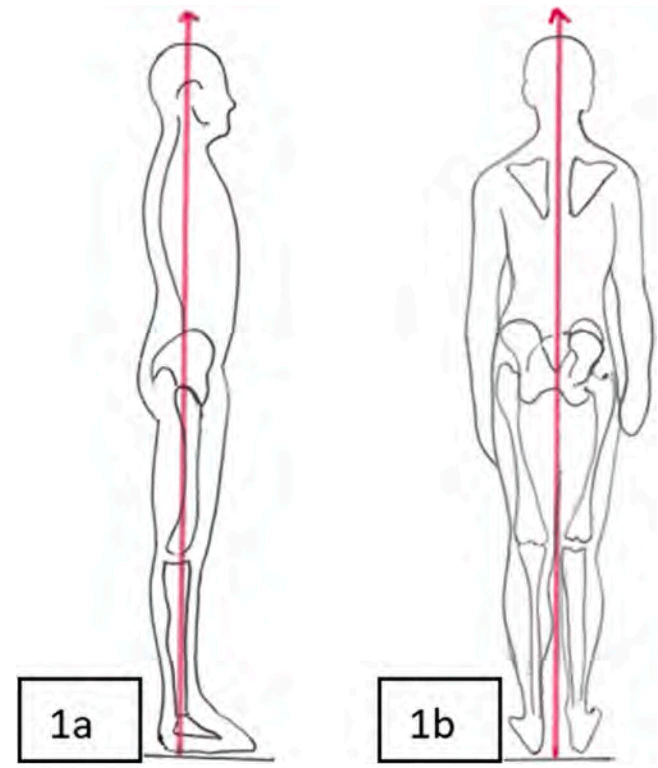

Fig. 1. a. Lateral view of ideal posture in a human. b. Midline view of ideal posture in a human.

of "postural control", which is the dynamic and complex process of maintaining posture (Shumway-Cook and Woollacott, 2007). "Muscle tone" refers to the force with which a muscle resists being lengthened and it is tested using passive flexion/extension of a relaxed limb in order to feel the resistance to movement (Shumway-Cook and Woollacott, 2007). Postural control involves the complex interaction of many components of the musculoskeletal and neurological systems and is influenced by the individual's interaction with the environment and the specific task (Shumway-Cook and Woollacott, 2007).

Motor processes, sensory/perceptual processes and higher-level processes all contribute to postural control (Shumway-Cook and Woollacott, 2007). Higher level control from regions of the brain can anticipate movement that is potentially destabilising (Shumway-Cook and Woollacott, 2007). Sensory input from visual, vestibular and musculoskeletal systems feedback information about the body segments' location and movement (Shumway-Cook and Woollacott, 2007; Hodges et al., 2013). Simple spinal cord mechanisms and more complex supraspinal pathways in the nervous system integrate sensory input and plan coordinated and timed motor output (Hodges et al., 2013).

The properties of muscle, joint range-of-movement, flexibility and biomechanics also contribute to postural control (Shumway-Cook and Woollacott, 2007). The muscle activity required to maintain postural control is not just based on moving a muscle's origin in relation to its to insertion (Petty and Moore, 1998; Janda et al., 2007; Shumway-Cook and Woollacott, 2007). It also requires precisely timed and coordinated muscle action in relation to other structures, to control movement of the body segments around joints and to counteract gravity; taking into account the stabilising role of muscle (Petty and Moore, 1998; Shumway-Cook and Woollacott, 2007). The correct duration and combination of forces must be attained to maintain the appropriate joint position; termed the neutral zone (Panjabi, 1992).

The peak tension a muscle can generate occurs at its functional resting length, termed the muscle length-tension relationship (Sandercock and Heckman, 2000; Comerford and Mottram, 2001). Changes in muscle activity can alter the muscle functional length if the resting length is shorter or longer than the optimum (Kendall et al., 1993; Sandercock and Heckman, 2000; Sahrnman et al., 2017). The resting length of a muscle can adapt habitually by a consistent change in the joints' or segments' position in relation to each other, causing the muscle to become shortened or elongated (Kendall et al., 1993; Comerford and Mottram, 2001; Sahrmann et al., 2017).

Measurement of postural control

Objective measurement of postural stability/control, termed posturography, involves analysis of the sway and migration of the centre of pressure (COP) with force platforms or pressure mats (Manera et al., 2017; Carillo et al., 2018; Humphries et al., 2020a; Humphries et al., 2020b). Other variables measured include centre of mass (COM), centre of gravity and base of support (Table 1).

The COM motion is controlled by forces generated by muscles and coordinated by the nervous system (Shumway-Cook and Woollacott, 2007). In stance the COP moves around the COM to keep it within the base of support (Fig. 2.) (Shumway-Cook and Woollacott, 2007). Ideally, in the standing human the COP will be at the point where the plumb line bisects the floor in Fig. 1. (Shumway-Cook and Woollacott, 2007). In the standing dog, the COP relates to the net ground reaction forces considered either through one limb or through the whole body (Lopez et al., 2019; Carillo et al., 2018). The COP does not provide information on the position or responses of the body segments required to keep the COP within the base of support (in either species).

Existing canine posture research

Measurement of posture and COP

A search of the veterinary literature with keywords including 'canine' 'posture' 'centre-of -pressure', up to and including the year 2023, revealed the measurement of COP has been the main focus of previous studies related to dogs' posture. Statokinesiograms present the area that includes 90% of the points during the COP sway in a 2D space (Carillo et al., 2018). Stabilograms show the migration of the COP in the vertical and horizontal axes (Carillo et al., 2018). The mean speed of movement of the COP; mean distance of the centre point of all COP points (COP- radius); the COP excursion index quantifying the mediolateral and craniocaudal displacement of the COP, are all measurable

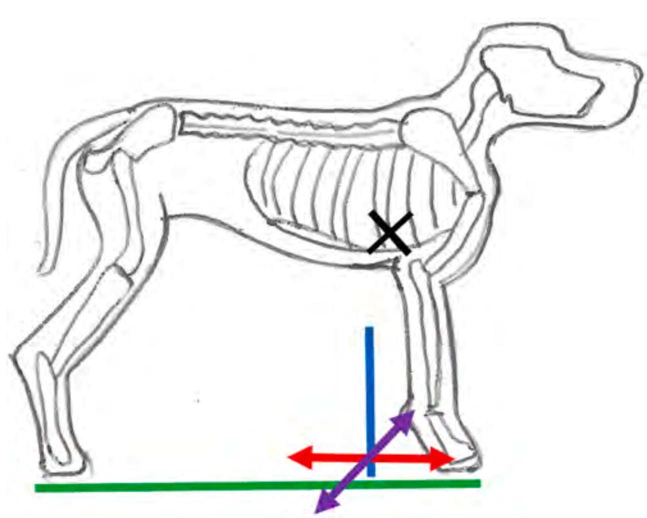

Fig. 2. Schematic representation of Centre of Mass (COM) marked with black X, Base Of Support (BOS) marked with green line, mean Body Centre Of Pressure (COP) marked with blue line, Cranio-caudal COP movement marked as red arrow, Medio-lateral COP movement marked as purple arrow.

parameters of the COP of the body and within a limb (Charalambous et al., 2023). COP can be measured in relation to the whole body, or within the limb or within the paw. Pedobarography analyses the static or dynamic pressure distribution within the paws and is also carried out on a pressure mat (Lopez et al., 2019).

Measuring postural stability in standing dogs on a motorized training platform has it's challenges as described by Lutonsky et al. (2023). The largest increase in COP parameters was with amplitude of displacement of the COP rather than speed. Optimal postural stability challenge would be via increase in the speed and amplitude setting of the platform but this was not tolerated by the dogs (Lutonsky et al., 2023). Reicher at al., (2020 describes the process for measuring COP in dogs: the dog needs to be relaxed in the environment where the study is taken place and an even gait pattern in a dynamic COP study is required for five consecutive trials without the dog pulling on a leash. In the standing studies each condition was measured for one minute (a minute break in between each measurement to avoid fatigue) and repeated three times on three separate days (with at least two days in between) (Lutonsky et al., 2023).

The COP has been measured in dogs both statically and dynamically with pressure mats (Manera et al., 2017; Carillo et al., 2018; Humphries et al., 2020; Shaheen et al., 2023) and on treadmill imbedded force plates, as well as with kinematic measurements (Blau et al., 2017; Lewis et al., 2019; Shaheen et al., 2023). Measurements of body COP on force platform and pressure mat systems in standing, healthy Dachshunds were comparable for anterior-posterior and medial-lateral ranges, and 95% area of best fit ellipse, but not for sway path (Shaheen et al., 2023). The direction of body COP sway in sound dogs of varying breeds has been shown to be dominant in the latero-lateral axis (Manera et al., 2017; Carillo et al., 2018) whereas it has an anterior-posterior orientation in humans (Blaszczyk, 2016).

Lameness can affect the COP. The sway and migration of the body COP has been shown to increase in lame dogs with unilateral elbow dysplasia and cranial cruciate disease (Carillo et al., 2018). Dogs with joint pain and conscious proprioceptive deficits showed increased acceleration of body COP in the cranio-caudal direction (Mondino et al., 2022). There was a higher displacement of body COP in older dogs compared to younger ones indicating postural sway increased with age (Mondino et al., 2022). Additionally, pedobarographic measurements have been demonstrated to be higher in the sound limb of dogs with elbow dysplasia (Carillo et al., 2018; Lopez et al., 2019) and cranial cruciate disease (Carillo et al., 2018). Paw COP area and displacement differ depending on whether a dog has elbow osteoarthritis or hip osteoarthritis (Reicher et al., 2020). These differences extended beyond the affected limbs, were consistent with other findings (Lopez et al., 2019; Braun et al., 2019) and contributed to the potential development of the COP as a diagnostic tool in future (Reicher et al., 2020). These studies consider the mechanical changes in COP measurements but do not relate this to functional change in the dog's posture.

External challenges to COP in dogs have been explored. The speed of COP within the paws of dogs walking over one and two obstacles was slower in the pelvic limbs, and unchanged in the thoracic limbs (Charalambous et al., 2022). It was suggested this represented a more controlled movement of the pelvic limbs, potentially because more movement planning and working memory were required to guide them over the obstacle after the thoracic limbs and with less visual reference (Charalambous et al., 2022). The speed of COP within the thoracic limbs in heelwork was increased (Charalambous et al., 2023). The area of the COP in the thoracic limbs was greater when dogs wore rubber boots (on all four, or individual paws) (Bieber et al., 2022). The greater thoracic limb paw COP was thought to be due to greater instability with the boots on (Bieber et al., 2022). The migration of the COP within the paw was only in the mediolateral direction, never craniocaudal (Beiber et al., 2022). Body COP has been challenged in standing using external mechanical perturbations from a training platform, successfully increasing all COP parameters (Lutonsky et al., 2023). The amplitude of the perturbation had a greater effect on COP than the speed, showing more challenge to the dogs' postural stability (Lutonsky et al., 2023).

It is important for physiotherapists and specialists in veterinary rehabilitation and sports medicine to understand that the body COP location differs between breeds; for example, in standing, it is located more cranially in sound Labrador retrievers than in sound German shepherds (Humphries et al., 2020a). This could be explained by German shepherds having greater flexion through stifle and hock joints (Humphries et al., 2020a; Humphries et al., 2020b). Other differences reported in body COP location include that it is more cranial in dogs with pelvic limb paresis (Lewis et al., 2019), and that older, heavier healthy Dachshunds (not senior, nor obese) have more stable stance postures (Shaheen et al., 2023). However postural sway increased with age in another study and in dogs with joint pain (Mondino et al., 2022). The measurement of the distribution of thoracic limb to pelvic limb weight bearing may reflect postural adaptation and can be influenced by pathology; English bulldogs with severe elbow dysplasia have shown a reduction in thoracic limb static weight-bearing and an increase in pelvic limb loading (Mölsä et al., 2020).

Posture can be assessed in positions other than standing (Janda et al., 2007; Shumway-Cook and Woollacott, 2007). The quality and symmetry of sitting and lying positions, as well as pelvic limb weight bearing in standing, have been used to assess stifle-related function in dogs (Hyytiäinen et al., 2018). The quantification of compensatory solutions, such as in the Finnish Canine Stifle Index, relates to the postural adaption to compensate for the joint pathology (Hyytiäinen et al., 2018).

Posture versus conformation in the dog

In current literature, conformation is considered much more commonly than posture in dogs. Although conformation may influence posture, it is important to appreciate the difference between the structural profile of bones which is fixed, and the dynamic and coordinated relationship between position of the body segments (Czaprowski et al., 2018).

Symmetry between right and left sides of the dog in the sagittal plane is commonly considered within a veterinary and physiotherapy assessment. With a dog's quadrupedal stance involving a horizontally orientated spine, both dorsoventral and craniocaudal views of the dog's "midline" need to be considered within the sagittal plane. This will include asymmetries in limbs, but also incorporate the head, neck and spine. The relationship of the body segments in the coronal plane (viewing the dog from one side) seems to have less focus in dogs, although work by Stark et al. (2021) did explore this plane by reviewing the scapula rather than the shoulder joint position, and diagrams produced suggested the pelvis is slightly higher in relation to the scapula in beagles.

Breed variation in spinal posture

Labrador retrievers have been shown to have a significantly more extended mid-thoracic angle in stance, and in trot, a more extended thoracolumbar angle and less flexed lumbosacral angle than German Shepherd (Humphries et al., 2020a). The greater lumbosacral flexion in German Shepherd was attributed to their increased hock and stifle flexion angles and shorter tibial length than the Labrador retrievers' (Humphries et al., 2020a). However, that study did not consider whether the difference in spinal posture was related to structural difference at a morphological level within the spine or functional change in relationship of the spinal segments.

The degree of spinal slope versus curvature of the spine in German Shepherd can influence thoracic limb position and contact area suggesting that the spinal position can affect limb loading (Humphries et al., 2020b). German Shepherds with a greater back slope have their thoracic limbs placed closer together and have an increased thoracic limb contact area (Humphries et al., 2020b). In standing the angulation of the pelvic limb joints, within the two types of spinal posture in German Shepherds described, has not been reported to correlate with pelvic limb joint angles.

Evidence of the adaptation of the neuromuscular system to compensate for conformation and posture has been found in Dachshunds (Boström et al., 2019). The shorter leg length to back length in Dachshunds requires greater spinal stiffness than the shorter backed, longer limbed Border terrier (Boström et al., 2019). This stiffness is created by postural and dynamic stability from the epaxial muscles (Boström et al., 2019). Conversely the adaption of a longer fascicle length in the Border terrier epaxial muscles may to be due to greater leverage from the longer pelvic limbs (Boström et al., 2019).

Spinal malformations may also affect posture in dogs, as reported in the thoracic spine in French bulldogs, Pugs (Ryan et al., 2017) and English bulldogs (Ryan et al., 2017; Mölsa et al., 2020). Kyphosis and scoliosis are both structural issues affecting spinal morphology that will affect spinal posture and limb loading: in one study, vertebral kyphosis affected the total pressure index in French bull dogs with normal neurology whereas dogs with vertebral kyphosis shifted weight from the pelvic limbs onto the thoracic limbs (Wyatt et al., 2019). The effect of conformation on postural stability has not yet been studied in dogs.

Postural dysfunction

The human physiotherapy literature states that dysfunctional or abnormal posture can often be indicative of strategies to avoid pain or compensate for weakness, altered balance, coordination, or restriction (Kendall et al., 1993; Janda et al., 2007; Shumway-Cook and Woollacott, 2007; Sahrmann et al., 2017). Consideration of these factors is also important in the physiotherapy assessment of dogs; being quadrupeds, dogs have twice the limb anatomical stabilisation points in standing than humans. The human physiotherapy literature also states continued poor movement patterns and poor posture can create an imbalance in the normal activity of the muscle groups (Comerford and Mottram, 2001; Janda et al., 2007; Hodges et al., 2013) and consequently adaptation in opposing muscle and other tissues (Sahrmann et al., 2017). This adaptation can create more permanent changes in posture which may become a primary issue, or perpetuate an ongoing secondary issue (Sahrmann et al., 2017).

Variations from the ideal posture have been categorised/classified in human physiotherapy (Kendall et al., 1993; Janda et al., 2007). Examples of this include kyphosis-lordosis posture, flat back posture, sway back posture (Kendall et al., 1993), and lower (or pelvic) crossed syndrome, layer syndrome (Janda et al., 2007). These common patterns of dysfunctional posture consider the altered position of each joint or body segment in relation to each other, and in regard to the 'plumbline' (Kendall et al., 1993). For example, the "sway back posture" describes the occurrence of posterior displacement of upper trunk, lumbar flexion, hyperextended hip joints with anterior displacement of the pelvis, hyperextended knees, and neutral ankles (Kendall et al., 1993).

These altered joint and segmental relationships can stress the surrounding muscle groups causing them to become 'tight' or 'weak' (Janda et al., 2007) or shortened or elongated (Sahrmann et al., 2017). Muscle imbalance is the altered relationship between muscles that are prone to inhibition (underactivity) or weakness and those that are prone to tightness (overactivity) or shortness (Janda et al., 2007). Considering the postural dysfunction category such as 'sway back posture" mentioned above, the muscle changes involve elongated and weak hip flexors, external obliques, upper back extensors and neck flexors, short and strong hamstrings, upper fibres of internal oblique abdominals, and strong lumbar paraspinal muscles (Kendall et al., 1993). This postural analysis provides information to the physiotherapist and specialist in veterinary rehabilitation and sports medicine regarding the dysfunction of the muscles and can then be related to identifying and addressing movement dysfunction (Comerford & Mottram, 2001b; Janda et al., 2007; Sahrmann et al., 2017).

Dysfunctional posture in the dog

Similar categorized or defined systems relating posture and muscle function as described above in humans, do not yet exist in the dog. Generally, muscle function is determined by multiple factors including location (origin, insertion, number of joints involved), joint angle change/length tension, innervation, its architecture and characteristics, and contraction type (Soderberg, 2007). Information on canine muscle function is available: the muscle function of the canine epaxial muscles (Boström et al., 2019; Webster et al., 2014), thoracic limb muscles (Williams et al., 2008a), and pelvic limb muscles (Shahar and Milgram, 2010; Williams et al., 2008b), has been investigated by analysing muscle architecture parameters and moment arms. Fibre type composition has been reported in m. latissimus dorsi (Mannion et al., 1986; Lucas et al., 1992) and m. longissimus dorsi (Štrbenc et al., 2003) to be predominantly type II. The gluteus medius muscle in German Shepherds had a higher percentage of type II to type I muscle fibres (Braga et al., 2016). Electromyography (EMG) related data on the quadriceps muscle group (Araújo et al., 2016; McClean et al., 2019), gluteus medius (Bockstahler et al., 2012; Breitfuss et al., 2015 McClean et al., 2019), and longissimus as well as mm. multifidus (Schilling and Carrier, 2010), has been analysed during movement. Consideration of the role of muscle groups as "stabiliser" or "mobiliser" muscles has been proposed (Schilling and Carrier, 2010; Boström et al., 2019) but more information needs to be gathered and analysed regarding to the role of muscles in postural control in dogs.

An example of a dysfunctional posture in dogs is shown in Fig. 3 which shows a dog displaying an obvious increase in thoraco-lumbar spinal flexion and caudal pelvic tilt, a wide thoracic limb base-of-support, and a more narrow and flexed pelvic limb joint standing angle (Fig. 2). During physiotherapy assessment the variation in posture would be compared against what would be considered 'normal" for the breed. It would also be reviewed throughout different positions (ie. sit, lie) and during transitions of position (ie. sit to stand) and different gaits (ie. walk, trot, run) to see whether it is a 'fixed' strategy or whether segmental movement occurs.

The reasons a dog might adopt this posture are wide ranging. The dog may want to shift their COP more cranially onto the thoracic limbs because of bilateral pelvic limb pain, thus trying to offload their pelvic limbs. Equally they may have spinal or abdominal pain. They may also have pelvic and/or pelvic limb weakness, thus recruiting the trunk and abdominal muscles to stabilise the trunk, providing them with means to gain some stability and to move forward. The physiotherapist needs to evaluate the underlying reason for the posture in order to address it appropriately from a treatment plan perspective. This plan may also involve referral back to a veterinarian if it is not a physiotherapy issue.

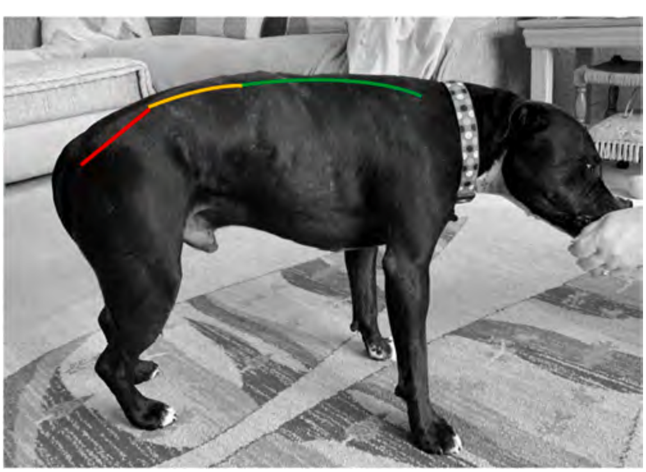

Fig. 3. Dysfunctional posture in a dog. Diagram showing the increased thoracic and lumbar spinal flexion and more caudally tilted pelvic position.

An outline of an intervention strategy

Visual identification of abnormal posture during a physiotherapy assessment should prompt a full static and dynamic assessment. This visual assessment would consider the position of each of the segments within the limbs, and the cervical, thoracic and lumbar and pelvic segments in turn, in a static position. The relationship of these segments would then be monitored (visually and/or through palpation) as the dog moves into different positions, through transitions and at different gaits. For example, increasing the size of the dog's base of support to assess whether there is improvement in the relationship between the body segments, would suggest the possibility an underlying dynamic instability issue. If the postural dysfunction remained fixed through movement more of a concern regarding pain might be considered, or the possibility of a structural (conformational) variation for example.

Visual assessment would also include consideration of the dog's behaviour and emotional state on their presenting posture; a dog presenting with the tail tucked underneath, a flexed thoracolumbar spine and/or a crouched pelvic limb stance may be anxious (Clay et al., 2019). Equally, the dog may be in pain or have underlying orthopaedic or neurological pathology.

Within the palpatory assessment the physiotherapist would aim to identify any overactive and / or underactive (inhibited) muscle groups (and related myofascia). Muscle hypertrophy and atrophy, as well as muscles' resting length would also be noted. The information gathered would be considered in the context of, and with consideration of, any pathology that had been diagnosed by the veterinarian.

The careful selection of motor relearning exercises to ensure that the compensatory posture is not compounded by overchallenging the dog's neuromotor control is essential. This is achieved by using appropriate techniques to increase muscle activation specifically where the focal weakness or inhibition is found, but also to simultaneously de-recruit the overactive muscles groups (Shumway-Cook and Woollacott, 2007). This may involve soft tissue release (i.e. myofascial release, trigger point release, massage) or stretching for example to address adaptive shortening (Janda et al., 2007; Sahrmann et al., 2017). Alternatively, techniques to modify tone in a neurological case could be used (Shumway-Cook and Woollacott, 2007). When selecting exercises the focus is on ensuring the compensatory posture is not exacerbated (Shumway-Cook and Woollacott, 2007). This is achieved by careful implementation of each exercise with the appropriate baseline assessment and grading of the level of challenge, which require robust outcome measures and frequent re-evaluation'. Facilitatory handling techniques will help guide muscle recruitment/de-recruitment. Then close monitoring of the dog's postural adaptation to the challenge of the exercise will help ensure only the desired muscles are targeted for increased recruitment.

Conclusions

Recognition of normal posture and postural dysfunction is a key part of canine physiotherapy assessment. A better understanding of what is to be considered 'normal posture' in the dog, how this relates to COP and acknowledging breed differences, is required. Functional analysis of the altered movement patterns and compensations causing the posture is essential to treatment planning to ensure that the implemented intervention is safe, effective and specific to the dysfunction identified.

To better understand the role of various structures as components of posture and postural control, research combining posture and muscle architectural information and functional analysis is needed.

CRediT authorship contribution statement

Heli K. Hyytiäinen: Writing – review & editing, Writing – original

draft, Visualization, Supervision, Project administration, Methodology, Conceptualization. **Catherine M. McGowan:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Conceptualization. **Hannah E. Michael:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Conceptualization.

Declaration of Competing Interest

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

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Effect of Transcutaneous Electrical Nerve Stimulation on Gait Parameters in Dogs with Osteoarthritis

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Simple Summary: Although scientific evidence for treatment efficacy is lacking, transcutaneous electrical nerve stimulation is used in dogs as a pain-relieving treatment. This randomised single-blinded cross-over study aims to investigate whether treatment with transcutaneous electrical nerve stimulation will affect gait parameters in dogs with osteoarthritis. Fifteen dogs were included in the study, and all dogs were over one year of age, lame, and had chronic pain for more than three months. The dogs were treated with transcutaneous electrical nerve stimulation for seven or ten days, and their gait pattern in trot was evaluated with a pressure-sensitive mat. In the present study, no significant differences were seen between transcutaneous electrical nerve stimulation and placebo treatments for any of the gait parameters evaluated by the pressure-sensitive mat. Further studies are needed to confirm the observations.

Abstract: Osteoarthritis is a common degenerative disease in dogs, often manifested as pain, joint swelling, and lameness. Despite the lack of scientific evidence for its treatment efficacy, transcutaneous electrical nerve stimulation (TENS) is used in dogs as a pain-relieving treatment. This randomised single-blinded cross-over study investigated the effect of TENS on gait parameters in fifteen dogs with osteoarthritis. Stance time, swing time, stride time, stride length, peak vertical force (%BW), vertical impulse (%BW*sec), and symmetry indices were obtained using a pressure-sensitive mat. TENS treatment of 80 Hz and 100 µs with an individually selected amplitude was conducted for 45 min once daily for a treatment period of seven or ten days. No significant differences were seen between TENS and placebo for any of the gait parameters. Hence, in this study, TENS did not affect gait parameters, compared to placebo. Further studies are needed to confirm the observations.

Keywords: TENS; pressure sensitive mat; locomotion; lameness; electrotherapy; kinetic; canine; pain; rehabilitation; musculoskeletal system

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1. Introduction

Osteoarthritis (OA) is a common degenerative disease in dogs, with a possibly long-term need for therapy [1–4]. It is usually manifested as pain, joint swelling, and reduced joint mobility, causing varying degrees of lameness [5–7]. Joint pain may lead to pain-induced functional impairment, regarded as one of the clinical signs of OA [8]. There are several treatment strategies for OA, including pharmaceuticals, nutraceuticals, weight reduction, regenerative medicine, therapeutic exercises, and different rehabilitation modalities [9–14]. It is likely that the management of canine OA may benefit from an integration of both pharmacologic and non-pharmacologic treatments. Common pharmaceuticals for OA are nonsteroidal anti-inflammatory drugs (NSAIDs), corticosteroids, and monoclonal antibodies [11,15–17]. However, in 55% of the studies on NSAIDs, adverse effects are reported [18]. Even if the majority of adverse effects are mild, they may restrict long-term use of medication [15,17,19–22]. Further, concurrent disease may also restrict the use of corticoids [15,16,20]. Untreated pain causes suffering for the dog and has a negative impact on its welfare, as well as on the wellbeing of the owner, since managing a dog with chronic pain negatively affects their life [23]. Therefore, it is relevant to study non-pharmacologic treatments, such as different rehabilitation techniques, as complementary treatments, but especially as stand-alone treatments for those dogs that do not tolerate NSAIDs or corticosteroids and where treatment with monoclonal antibodies is not feasible.

Veterinary rehabilitation has attracted increased interest from dog owners and animal health staff in recent decades. Rehabilitation is considered an important component of an overall long-term treatment strategy for OA. Among different rehabilitation modalities, there is an increasing use of transcutaneous electrical nerve stimulation (TENS). TENS is a device that uses electric current, delivered though electrodes on the skin, to stimulate nerve fibers for therapeutic reasons, i.e., as pain relief. The specific treatment settings include adjustable parameters such as pulse frequency, pulse duration, and intensity. TENS is claimed to provide pain relief through either endogenous opioid release (low-frequency TENS) or on a segmental level by the use of the pain gate theory (high-frequency TENS) [24,25]. The latter is believed to be effective by applying stimuli to large diameter non-noxious afferents (A-beta), which subsequently reduces pain via decreased nociceptor activity [24,25]. Further, studies have shown an increase in β-endorphins and methionine-enkephalin in human subjects, a release of glutamate and substance P in animals with inflammation, neuropathic, or incisional pain, a reduction in pressure pain thresholds at the site of TENS and at sites outside the area of application, and a reduction in microglia and astrocyte activation in the spinal cord in both osteoarthritic and neuropathic pain animal models [26–29].

In humans, TENS is used as a pain-relieving treatment and a complementary or single treatment for OA [24,30–32]. A systemic review and meta-analysis of TENS for acute and chronic pain in humans, based on 381 studies, concluded that there was moderate-certainty evidence that pain intensity was lower during or immediately after TENS treatment compared to placebo [33]. The review included studies that used participant-reported strong but comfortable TENS sensation stimulation, with electrodes at the site of pain or over nerve bundles proximal to the site of pain. The effect was evaluated directly after treatment and with different types of pain scales [33]. However, other studies report no effect on pain compared to control [34–37]. Conflicting results and, thus, inconclusive evidence are explained by the low quality of relevant studies as well as the diversity in treatment protocols [37]. Regarding animal studies, studies report that TENS produced an analgesic effect in rodents with experimentally induced OA [38,39]. The scientific documentation on the effect of TENS in dogs is even sparser than in humans and laboratory animals. Thus, several authors report that there is a need for more canine studies [40–43]. The results from the few existing studies indicate that treatment with TENS may increase weight bearing on the affected limb in dogs with OA for up to 180 min, with the greatest significant difference immediately after treatment [42]. A study on dogs with canine ankylosing spondylitis showed a decrease in signs of pain evaluated by visual analogue scale and clinical examination after TENS treatment [40]. Further, a weight-reduction study on dogs with OA examined the difference in lameness in two treatment groups, both with dietary protocol, but with two different physical therapy programmes, one of which included TENS treatment. Results indicate that dogs that received an additional TENS treatment showed significant improvement, evaluated with force plate and changes in peak vertical force (PVF) and vertical impulse (VI), whereas dogs with no TENS treatment showed only significant improvement after 4 months [41,44]. Two of the previous studies have evaluated the effect of TENS by the use of kinetic techniques, i.e., pressure-sensitive mats and force plates; the latter is regarded as the gold standard for measuring ground reaction forces [45–53]. Recent studies have compared the results from these two kinetic techniques and report that they are equally reliable but not interchangeable [54–57]. Further, studies have shown a high agreement between repetitive measurements in individual dogs [58].

The use of these techniques enables the registration of different gait parameters, such as temporospatial parameters, peak vertical force (PVF), vertical impulse (VI), and symmetry indices (SIs) [7,56,59–62]. PVF and VI adjusted to bodyweight (% BW) show a low variability [56,60,61]. Thus, the kinetic techniques contribute, together with an orthopaedic examination, to a more objective lameness evaluation.

In OA, mild to moderate lameness is often seen, and kinetic studies show alterations in PVF and VI, as well as symmetry indices [7,47,63–66]. Studies on pain-relieving treatment of dogs with OA have used changes in PVF and/or VI as outcome measures, showing therapeutic effects such as an increase in load on the lame limb but also redistribution of weight to other limbs [45,67–74]. Further, registration of temporospatial parameters has been used, but results are rarely described [59,60,75].

Due to the increasing clinical use of TENS, together with the lack of research on its possible effects, the present cross-over study investigates the effect of TENS on canine gait parameters, evaluated with a pressure-sensitive mat. The null hypothesis is that, for dogs with OA, treatment with TENS will not affect gait parameters differently than placebo treatment.

2. Materials and Methods

The study consisted of two parts—part 1 (TENS and placebo intervention) and part 2 (an NSAID intervention)—see Figure 1. For the comparison of TENS and placebo treatment effect, a prospective, single-blinded, randomised, placebo-controlled, and cross-over design was utilised (Figure 1). A pilot study was conducted in order to test the study design (study part 1), consisting of seven days of treatment with TENS or placebo performed by animal health personnel, and the pilot data were included in the final data. For the evaluation of the effect of NSAIDs (study part 2), a one-group pre-test–post-test study design was used (Figure 1).

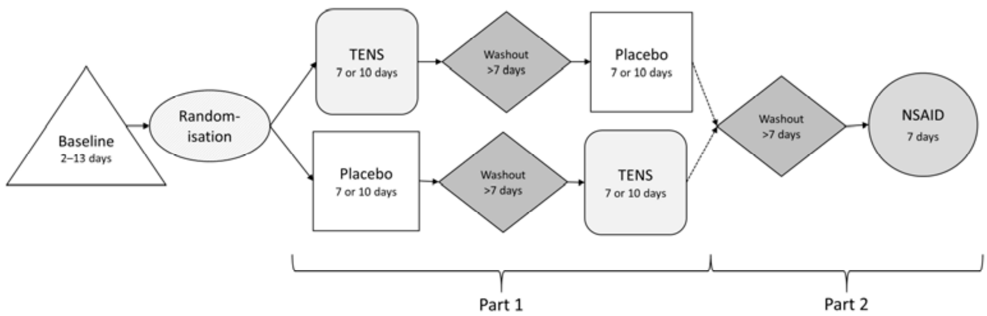

Figure 1. Schematic view of the study. The difference in length for the TENS and placebo treatment (7 or 10 days) depends on whether the dog participated in the pilot study (7 days).

Client-owned dogs of any sex or breed with confirmed OA were eligible for the study. Recruitment of dogs was conducted through social media (Facebook), through email posting and advertising in magazines, and at veterinary practices in the local area. Dogs were included if they were over 1 year of age, were 1–3 degrees lame in trot on a 5-degree scale at an orthopaedic examination, had an OA diagnosis confirmed by diagnostic imaging and had had chronic musculoskeletal pain (>3 months), diagnosed by a veterinarian before the study [76]. If the dog was diagnosed with OA in multiple joints, enrolment was based on the worst affected limb (referred to as the "lame limb") based on the dog's clinical history together with a clinical assessment and baseline/preintervention performed kinetic measurements.

Dogs were excluded if they had a metallic implant that interfered with treatment, a pacemaker or a tumour in the treatment area, or a sensory deficiency in the treatment area. The latter was assessed by palpation of the whole body and by manually stroking the skin at the selected localisations of the electrodes. Dogs were excluded from part 2 (NSAID intervention) of the study if they had a history of adverse reactions to NSAIDs.

Informed consent from the owners was signed and an ethical permit was granted by a source (information withdrawn as a result of blinding), and the study was performed according to guidelines established in the Helsinki Declaration [77]. The study included five to seven visits (measurement occasions) to the research facility, depending on participation in the NSAID part of the study (Figure 2). Registration on the pressure-sensitive mat was performed at each visit to the research facility. Data collection took place between September 2018 and January 2020.

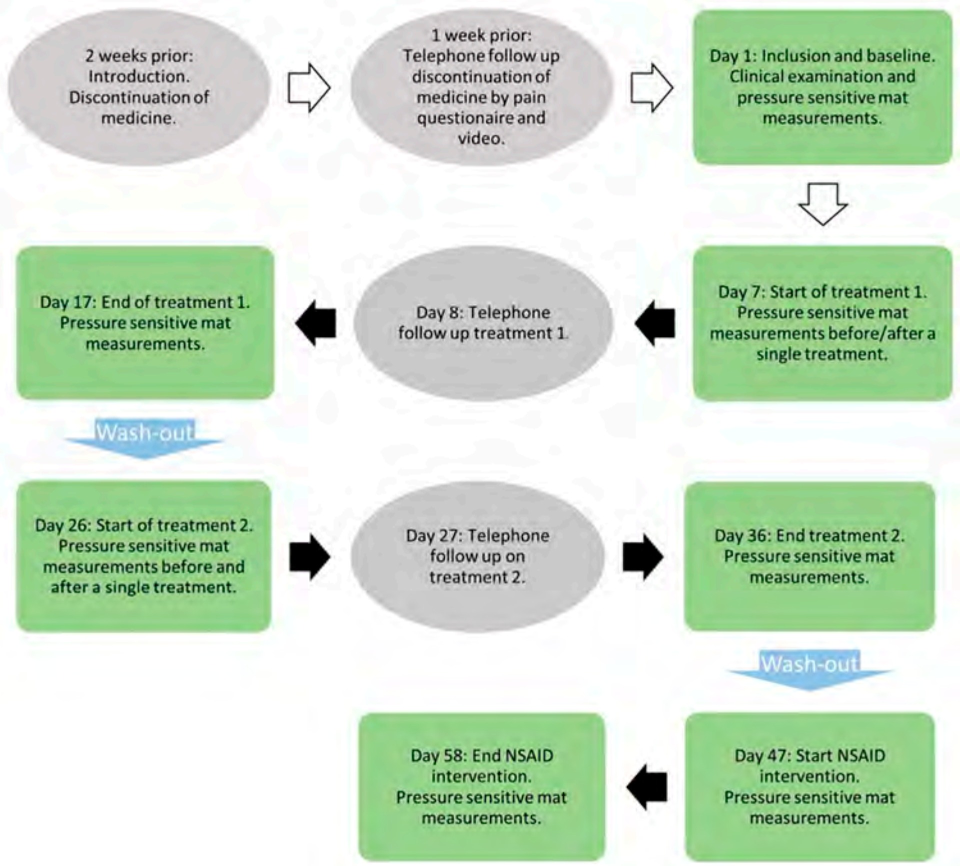

Figure 2. Study design and protocol. Grey ellipse = telephone contact. Green rectangles = physical visit. Black arrows = treatment period. Blue arrows = washout period.

2.1. Evaluation Methods

The dogs were evaluated via clinical examination, pressure-sensitive mat measurement and pain assessment questionnaires (Helsinki Chronic Pain Index and Canine Brief Pain Index). The pain index assessments were used during the baseline and throughout the study period to ensure animal welfare, especially after an eventual discontinuation of medication. In this article, results from the pressure-sensitive mat are presented.

2.1.1. Pressure-Sensitive Mat

A pressure-sensitive mat "Walkway High Resolution HRV4" (Tekscan Inc., Norwood, MA, USA) and software "Walkway Research ver. 7.60-31" (Tekscan Inc., Norwood, MA, USA) were used to collect the kinetic data. The measurements were made within an hour after the first treatment session (from now called "single treatment") and within 12–24 h after the last treatment of the whole treatment period ("multiple treatments"). The mat was regularly calibrated, and the calibration files used were coherent with each dog's weight.

The mat (195 × 45 × 0.57 cm) was placed in a corridor next to a wall and was covered with a 1 mm-thick non-slip plastic mat. Cameras filmed the dogs from a lateral and a craniocaudal aspect. The dogs trotted over the pressure-sensitive mat at a comfortable individual pace. The same handler and handler side was used in the absolute majority of measurements. A valid trial was defined as the dog's correct behaviour over the mat and the number of step cycles (a minimum of two step cycles/eight stances). Correct behaviour was defined as the dog trotting at a constant pace in a straight line, looking straight ahead with minimal intervention from the handler. It was subjectively assessed by the author(s) and noted in the data collection protocol. The criteria for successful kinetic data collection were three trials in trot (a 2-beat gait with left front (LF)/right hind (RH)-suspension-right front (RF)/left hind (LH) steps), with a velocity of between 1.5 and 2.2 m/s and an individual variance of <0.5 m/s.

The following gait parameters were registered: stance time, swing time, stride time, stride length, peak vertical force (%BW), vertical impulse (%BW), and symmetry indices based on peak vertical force.

2.1.2. Clinical Examination

To investigate if the dog met the inclusion criteria, a clinical examination was conducted by an experienced veterinarian.

2.1.3. Pain Questionnaires

Helsinki Chronic Pain Index and Canine Brief Pain Index were used as a control for animal welfare, especially after the discontinuation of pain-relieving medication [78–81]. The two pain questionnaires were answered by the owner or another person who had daily contact with the dog. The respondent was instructed to fill out the forms once a week to keep track of the dog's pain score and to contact the authors if the dog showed signs of deterioration.

2.2. Study Protocol

Telephone contact with eligible dog owners was made at both two weeks and one week before the start of the study. The suitability of the dogs was determined by the information the owners sent in when they expressed interest in the study. The first call focused on the retrieval of the dog's status and medication (Figure 2). Owners were asked to send in videos of their dog's locomotion from a lateral and cranial view in trot for an initial lameness assessment. Based on the video and the phone information, the study veterinary surgeon assessed if the dog's pain medication could be discontinued. Pain medication was reinstated before baseline if deemed necessary by the same veterinarian, based on pain questionnaires and owner information. For these dogs, pain medication was given throughout the study. If the medication was needed later in the study (i.e., after baseline), the dogs were excluded. The dog's status was checked one week prior to the start of the study via the second telephone call, pain questionnaires, and new videos. Owners could make additional contact with the study team when needed.

In part 1 of the study, each dog was allocated randomly into either TENS or placebo treatment for the first treatment period. The treatments were reversed during the second treatment period (Figure 1). A washout period of a minimum of ten days was used between the two treatment periods in study part 1. Part 2 of the study started after a washout period for those dogs that could withstand NSAID treatment. The NSAID intervention consisted of a seven-day treatment.

2.2.1. Transcutaneous Electrical Nerve Stimulation and Placebo Treatment

Treatment was administered with either one of two TENS machines—Profile TENS (Body Clock Health Care Limited, London, UK) or a Cefar TENS Chattanooga (Enovis, Lewisville, TX, USA)—using CEFAR coal fibre electrodes (3 × 5 cm) (Enovis, Lewisville, TX, USA). The treatment programmes of the two TENS devices were synchronised so that the settings were identical. The skin was clipped precisely where the electrodes were situated during treatment, soaked with water and ultrasound gel was used as a transmitting substance. Two electrodes, a minimum of 4 cm apart, were placed on intact skin, with electrodes at the site of pain (distal placement) or over nerve bundles proximal to the site of pain (proximal placement).

The first treatment was conducted partly by animal health staff and partly by the owner under the supervision of the animal health staff. During the following treatments, the dogs were treated by their owners, except for the pilot study, where the treatments were conducted by animal health personnel. The treating person, mainly the owner, received instructions both verbally and in writing before each treatment period (TENS and placebo) regarding how to perform the treatment. Optional additional supervision was offered by one of the authors.

The TENS device was set to a constant current with a frequency of 80 Hz and a pulse duration of 100 µs based on previous studies and clinical experience. The intensity (amplitude, unit milliampere (mA)) was increased until muscular fasciculation in the treatment area's muscles occurred and was lowered if the dogs expressed discomfort. The intensity was then gradually increased during the treatment session to maintain sensation throughout. The treatment sessions were 45 min once daily. The treating person kept a diary of each treatment session, including treatment duration, electrode placement, used intensity, and behaviour of the dog. The placebo treatment protocol was identical to the TENS treatment, with the exception that the device was not switched on. Each treatment period's length was ten days, except for the pilot study, where the dogs were treated for seven days.

2.2.2. NSAID Treatment

Firocoxib was administered orally by the owner once daily for seven days after the finalisation of the TENS part of the study. A dosage of 5 mg per kg body weight was subscribed based on the recommended dosage by the manufacturer [82]. Owners were instructed to start the medication eight days before the final measurements of the NSAID treatment.

2.3. Data Management and Statistical Analysis

For all gait parameters, an average value based on three trials over the mat (a minimum of six step cycles/twenty-four stances) was included. If there were not three trials that met the inclusion criteria, the average value of two trials was used.

Three different symmetry indices (SIs) were used; either body quadrants, body sides, or body halves were compared. For the commonly used SI_{limb}, the quadrant containing the lame limb was compared to the contralateral quadrant, i.e., the sound limb, and the $SI_{sagittal}$ was compared to the left and the right sides of the body. The additional $SI_{transversefront}$ compared front limbs from front limb lame dogs with their sound hindlimbs, and the $SI_{transversehind}$ compared hindlimbs from hindlimb lame dogs with their sound front limbs.

SIs were calculated from peak vertical force (%BW) by using the following equation:

$$SI_{limb} = \frac{\text{lame limb}}{\text{contralteral sound limb}}$$
$$SI_{sagittal} = \frac{\text{front and hindlimb from lame body side}}{\text{front and hindlimb from sound body side}}$$
$$SI_{transversefront} = \frac{\text{front limbs from lame body half}}{\text{hindlimbs from sound body half}}$$
$$SI_{transversehind} = \frac{\text{hindlimbs from lame body half}}{\text{front limbs from sound body half}}$$

Differences in gait parameter values before and after treatment with TENS and placebo, respectively, were compared. The comparison was made on data collected before and after the first treatment session and before and after the last day of the whole treatment period for TENS and placebo; hereafter, the terms "single treatment" and "multiple treatments" are used. Further, differences in gait parameters were compared before and after the last day of NSAID treatment.

The data were compiled in Excel (Microsoft Excel 2016 (16.0.5443.1000), Microsoft Corporation, Redmond, WA, USA), and the statistical analysis was made in R (version 4.1.2 (2021-11-01)—"Bird Hippie", R Core Team, Vienna, Austria). The individual data and history of disease of the participating dogs are presented descriptively. The pressure-sensitive mat data were analysed in a linear mixed-effects model for a 2 × 2 cross-over design for the TENS and placebo part, with gait parameters (stance time, swing time, stride time, stride length, peak vertical force (%BW), vertical impulse (%BW*sec), and symmetry indices) as continuous outcomes. For the NSAID intervention, a linear regression model was used with gait parameters (stance time, swing time, stride time, stride length, peak vertical force (%BW), vertical impulse (%BW*sec), and symmetry indices) as continuous outcomes. In the linear mixed effects model, dog was set as a random effect, and age, sex, weight, simultaneous NSAID treatment, and velocity were set as fixed effects for all parameters except for the symmetry indices where age, velocity, and simultaneous NSAID treatment were excluded from the fixed effects due to restriction of numbers of factors in the model. Residuals were normally distributed. The significance level was set to $p < 0.05$.

3. Results

3.1. Descriptive Statistics

A total of 38 dogs were initially selected for the study. Of these, 26 matched the inclusion criteria and were enrolled in the study, and data from 15 of these dogs were finally used in the study. Of the 26 enrolled dogs, two were lost to follow-up, five were excluded due to unconfirmed diagnostic imaging diagnosis of OA, and two had to be excluded due to data corruption. Furthermore, two dogs had to be excluded: one due to an aggravated caudal cruciate ligament injury noted during baseline and the other due to the illness of the owner after one treatment period. One dog did not participate in part 2 of the study (NSAID intervention) due to a traumatic fracture of the elbow, so data from part 1 of the study were used. During part 2 (NSAID intervention), one dog needed to end the medication after five days due to suspected adverse reactions to the treatment, so the data from the NSAID intervention were excluded from the study.

The descriptive data of the dogs are presented in Table 1. The mean age was 6.8 years (±1.9 years). The mean weight was 22.7 kg (±9.4 kg). There were five mixed breeds: three Labrador retrievers and one each of Australian Cattle Dog, Beagle, Border Collie, Flatcoated Retriever, Malinois, medium-sized Poodle, and Staffordshire Bull Terrier. In part 1 (TENS and placebo intervention), one of the dogs received 7 days of treatment, and 14 dogs received 10 days of treatment. Two of the dogs were treated with NSAIDs during the whole study. Electrodes were placed at the site of pain (distal placement) in 14/15 dogs; in one dog, a placement over nerve bundles proximal to the site of pain (proximal placement) was made.

Table 1. Descriptive data of the dogs. OA = osteoarthritis, LF = left front limb, LH = left hindlimb, RF = right front limb, RH = right hindlimb, BF = both front limbs, BH = both hindlimbs, DP = distal placement electrodes, PP = proximal placement electrodes, L7S1 = 7th lumbar vertebra and sacrum.

Dog	Age (Years)	Breed	Weight (kg)	Lameness at Inclusion	Diagnosis and Electrode Placement	Number of Days of Treatment	NSAID Treatment through the Whole Study
Dog 1	8	Beagle	13	1° LH	OA stifle LH. Cruciate ligament injury LH. DP.	7	No
Dog 2	8	Labrador Retriever	31	2° LF	OA metacarpal joint phalanx 4 and 5 LF, phalanx 5 RF and elbow LF. DP.	10	Yes
Dog 3	6.5	Poodle, medium size	7	1° LF	OA elbow LF. DP.	10	No
Dog 4	8	Malinois	27	1° LF	Moderate OA shoulder LF. Mild OA shoulder RF. Disc herniation L7S1. DP.	10	No
Dog 5	3	Mixed breed	15	1° LH	OA stifle LH. DP.	10	No

Table 1. *Cont.*

Dog	Age (Years)	Breed	Weight (kg)	Lameness at Inclusion	Diagnosis and Electrode Placement	Number of Days of Treatment	NSAID Treatment through the Whole Study
Dog 6	8	Mixed breed	41	2° RH	OA stifle BH. DP.	10	No
Dog 7	6	Mixed breed	18	1° LH	OA hip BH. DP.	10	No
Dog 8	8	Border Collie	16	1° RH	OA lumbar spine. OA shoulder and phalanx BF. PP.	10	No
Dog 9	8	Labrador Retriever	37	3° RF	OA carpus and phalanx BF. OA hips BH. DP.	10	Yes
Dog 10	5	Mixed breed	17	3° LF	OA elbows and phalanx BF. Spondylosis spinal cord. DP.	10	No
Dog 11	7	Flatcoated Retriever	26	1° LF	OA carpus RF. Lameness LF. DP.	10	No
Dog 12	2	Labrador Retriever	30	1° LF	Fragmentation of processus coronoideus medialis elbow LF. OA elbow LF. DP.	10	No
Dog 13	7	Staffordshire Bull Terrier	13	1° LF	OA stifle LH. Operated cruciate ligament injury BH. Elbow dysplasia grade 2 BF. Hip dysplasia BH. DP.	10	No
Dog 14	9	Mixed Breed	30	1° LH	OA hips BH. OA lumbar spine. DP.	10	No
Dog 15	8	Australian Cattle Dog	20	1° LH	OA tarsus LH. DP.	10	No

3.2. Gait Parameters

The data were collected from a total of 108 measurement occasions (visits to the facility). Three trials per dog were included from 105 of the 108 measurement occasions. For the remaining three occasions, two trials (a minimum of four step cycles/sixteen stances) were used due to incomplete registrations. The mean value for a trial for all the dogs was 8.8 (range 8–12) stances, which corresponds to two step cycles. The same handler was used for 103 of 108 measurement occasions, and the handler was on the same side of the dog in 104 out of 108 occasions. The dogs trotted over the pressure-sensitive mat between 2 and 20 times (trials) on each measurement occasion.

No significant differences were seen between TENS and placebo treatments for stance time, swing time, stride time, stride length, peak vertical force (% BW) and vertical impulse for (% BW*sec) for any of the limbs. Similarly, no significant differences were seen, comparing before and after NSAID treatment, for stance time, swing time, stride time, stride length, and peak vertical force (% BW). However, the results show a significant increase in vertical impulse (% BW*sec) for the ipsilateral limb ($p = 0.02$). Estimated mean values and p-values for the gait parameters can be seen in Table 2.

No significant differences were seen for the SIs, either for single or multiple treatments, between TENS and placebo treatments. The NSAID treatment period showed no significant difference between before and after for any of the SIs. The mean values and significance for the symmetry indices can be seen in Table 3.

In order to further visualise the individual differences between TENS and placebo, the individual SI values are presented in spaghetti plots in Figure 3.

Table 2. Estimated mean values, number of dogs and *p*-value for the different gait parameters. SD = standard deviation. N = number of dogs. Sec = seconds. Cm = centimetre. %BW = percentage of body weight. Single = measurement after a single treatment. Multiple = measurement after multiple treatments. ** = significant *p*-value ($p < 0.05$).

Parameter	Time	Leg	TENS (Mean ± SD)	N	Placebo (Mean ± SD)	N	*p*-Value	NSAID (Mean ± SD)	N	*p*-Value
Stance time (sec)	Before	Lame	0.19 ± 0.04	15	0.20 ± 0.04	15		0.18 ± 0.04	9	
		Contralateral	0.20 ± 0.04	15	0.20 ± 0.04	15		0.19 ± 0.03	9	
		Ipsilateral	0.19 ± 0.04	15	0.20 ± 0.04	15		0.19 ± 0.05	9	
		Diagonal	0.20 ± 0.04	15	0.20 ± 0.04	15		0.19 ± 0.05	9	
	After single	Lame	0.20 ± 0.04	15	0.19 ± 0.04	15	0.80			
		Contralateral	0.20 ± 0.04	15	0.20 ± 0.04	15	0.87			
		Ipsilateral	0.20 ± 0.04	15	0.19 ± 0.04	15	0.14			
		Diagonal	0.20 ± 0.04	15	0.19 ± 0.04	15	0.19			
	After multiple	Lame	0.20 ± 0.04	15	0.19 ± 0.04	15	0.67	0.19 ± 0.04	10	0.66
		Contralateral	0.20 ± 0.04	15	0.19 ± 0.04	15	0.42	0.19 ± 0.03	10	0.36
		Ipsilateral	0.19 ± 0.04	15	0.19 ± 0.04	15	0.98	0.19 ± 0.04	10	0.20
		Diagonal	0.20 ± 0.04	15	0.19 ± 0.04	15	0.35	0.19 ± 0.04	10	0.06
Swing time (sec)	Before	Lame	0.25 ± 0.04	15	0.25 ± 0.04	15		0.25 ± 0.04	9	
		Contralateral	0.25 ± 0.04	15	0.25 ± 0.04	15		0.25 ± 0.04	9	
		Ipsilateral	0.26 ± 0.03	15	0.26 ± 0.03	15		0.25 ± 0.03	9	
		Diagonal	0.25 ± 0.03	15	0.26 ± 0.04	15		0.24 ± 0.04	9	
	After single	Lame	0.25 ± 0.03	15	0.26 ± 0.03	15	0.26			
		Contralateral	0.25 ± 0.04	15	0.25 ± 0.04	15	0.19			
		Ipsilateral	0.26 ± 0.03	15	0.26 ± 0.03	15	0.86			
		Diagonal	0.26 ± 0.03	15	0.26 ± 0.03	15	0.08			
	After multiple	Lame	0.25 ± 0.03	15	0.25 ± 0.04	15	0.58	0.26 ± 0.04	10	0.80
		Contralateral	0.25 ± 0.04	15	0.25 ± 0.05	15	0.07	0.25 ± 0.04	10	0.33
		Ipsilateral	0.26 ± 0.03	15	0.25 ± 0.04	15	0.25	0.25 ± 0.03	10	0.63
		Diagonal	0.25 ± 0.03	15	0.26 ± 0.04	14	0.19	0.24 ± 0.03	10	0.39
Stride time (sec)	Before	Lame	0.44 ± 0.06	15	0.45 ± 0.07	15		0.43 ± 0.06	9	
		Contralateral	0.45 ± 0.06	15	0.45 ± 0.06	15		0.44 ± 0.07	9	
		Ipsilateral	0.45 ± 0.06	15	0.45 ± 0.06	15		0.44 ± 0.08	9	
		Diagonal	0.45 ± 0.06	15	0.45 ± 0.06	15		0.44 ± 0.07	9	
	After single	Lame	0.45 ± 0.06	15	0.45 ± 0.05	15	0.34			
		Contralateral	0.45 ± 0.06	15	0.45 ± 0.05	15	0.06			
		Ipsilateral	0.46 ± 0.06	15	0.45 ± 0.06	15	0.47			
		Diagonal	0.45 ± 0.06	15	0.45 ± 0.05	15	0.97			
	After multiple	Lame	0.45 ± 0.06	15	0.44 ± 0.06	15	0.28	0.44 ± 0.07	10	0.78
		Contralateral	0.44 ± 0.06	15	0.45 ± 0.07	15	0.25	0.44 ± 0.06	10	0.59
		Ipsilateral	0.45 ± 0.06	15	0.44 ± 0.06	15	0.29	0.44 ± 0.06	10	0.46
		Diagonal	0.45 ± 0.06	20	0.45 ± 0.07	15	0.24	0.44 ± 0.07	10	0.42

Table 2. *Cont.*

Parameter	Time	Leg	TENS (Mean ± SD)	N	Placebo (Mean ± SD)	N	*p*-Value	NSAID (Mean ± SD)	N	*p*-Value
Stride length (cm)	Before	Lame	88.96 ± 14.37	15	89.17 ± 13.80	15		87.36 ± 14.20	9	
		Contralateral	88.90 ± 14.35	15	89.07 ± 13.91	15		86.05 ± 14.90	9	
		Ipsilateral	89.23 ± 14.09	15	88.94 ± 13.52	15		87.71 ± 13.86	9	
		Diagonal	89.57 ± 14.46	15	89.38 ± 13.95	15		87.44 ± 14.54	9	
	After single	Lame	88.22 ± 14.09	15	90.47 ± 14.77	15	0.52			
		Contralateral	87.84 ± 14.06	15	91.04 ± 15.19	15	0.13			
		Ipsilateral	88.70 ± 14.31	15	90.38 ± 14.53	15	0.90			
		Diagonal	88.41 ± 14.05	15	90.76 ± 14.75	15	0.49			
	After multiple	Lame	88.86 ± 13.45	15	90.14 ± 15.18	15	0.50	87.90 ± 14.36	10	0.96
		Contralateral	88.40 ± 13.41	15	92.60 ± 16.00	15	0.06	87.39 ± 14.24	10	0.66
		Ipsilateral	89.03 ± 13.56	15	90.68 ± 15.52	15	0.67	87.98 ± 14.17	10	0.96
		Diagonal	88.53 ± 13.32	15	93.04 ± 16.37	15	0.07	87.97 ± 14.26	10	0.81
Peak vertical force (%BW)	Before	Lame	61.15 ± 16.48	15	62.08 ± 16.56	15		59.33 ± 21.59	9	
		Contralateral	71.47 ± 20.97	15	72.57 ± 20.68	15		68.03 ± 23.22	9	
		Ipsilateral	67.33 ± 22.68	15	69.05 ± 22.84	15		70.71 ± 18.81	9	
		Diagonal	68.15 ± 22.52	15	70.85 ± 23.43	15		69.10 ± 18.99	9	
	After single	Lame	60.47 ± 17.37	15	58.94 ± 12.03	15	0.57			
		Contralateral	68.87 ± 20.03	15	68.98 ± 15.19	15	0.79			
		Ipsilateral	67.60 ± 23.60	15	69.48 ± 28.22	15	0.81			
		Diagonal	67.55 ± 23.25	15	69.40 ± 28.90	15	0.82			
	After multiple	Lame	62.16 ± 17.73	15	61.31 ± 17.61	15	0.70	55.40 ± 16.09	10	0.07
		Contralateral	73.00 ± 20.99	15	69.49 ± 20.55	15	0.40	61.19 ± 16.90	10	0.08
		Ipsilateral	72.03 ± 31.30	15	66.89 ± 22.89	15	0.26	70.55 ± 26.86	10	0.33
		Diagonal	73.53 ± 30.14	15	67.84 ± 25.56	15	0.15	69.85 ± 27.11	10	0.31
Vertical impulse (%BW*sec)	Before	Lame	7.16 ± 2.70	15	7.60 ± 3.19	15		6.38 ± 3.07	9	
		Contralateral	8.49 ± 3.44	15	8.90 ± 3.86	15		7.53 ± 2.80	9	
		Ipsilateral	7.59 ± 3.16	15	7.89 ± 3.26	15		7.80 ± 3.30	9	
		Diagonal	7.76 ± 3.08	15	8.18 ± 3.14	15		7.92 ± 3.46	9	
	After single	Lame	7.14 ± 2.71	15	7.00 ± 2.63	15	0.72			
		Contralateral	8.26 ± 3.04	15	8.24 ± 3.24	15	0.88			
		Ipsilateral	7.66 ± 3.20	15	7.67 ± 3.43	15	0.97			
		Diagonal	7.79 ± 3.24	15	7.76 ± 3.38	15	0.99			
	After multiple	Lame	7.36 ± 2.87	15	7.09 ± 2.74	15	0.75	6.18 ± 2.74	10	0.28
		Contralateral	8.89 ± 3.34	15	8.10 ± 3.27	15	0.28	6.85 ± 2.52	10	0.37
		Ipsilateral	8.31 ± 4.87	15	7.36 ± 3.03	15	0.33	7.98 ± 3.96	10	0.02 **
		Diagonal	8.54 ± 4.76	15	7.54 ± 3.55	15	0.26	8.05 ± 3.96	10	0.18

Table 3. Estimated mean values, number of dogs, and *p*-value for symmetry indices of peak vertical force (%BW). SD = standard deviation. N = number of dogs. %BW = percentage of body weight. SI = symmetry index. SI_{limb} = lame limb/sound contralateral limb. $SI_{sagittal}$ = front- and hindlimb lame side/front- and hindlimb sound side. $SI_{transversefront}$ = lame front limbs/sound hindlimbs. $SI_{transversehind}$ = lame hindlimbs/sound front limbs. Single = measurement after a single treatment. Multiple = measurement after multiple treatments.

Parameter	Time	TENS (Mean ± SD)	N	Placebo (Mean ± SD)	N	*p*-Value	NSAID (Mean ± SD)	N	*p*-Value
SI limb Peak vertical force (%BW)	Before	0.87 ± 0.11	15	0.87 ± 0.11	15		0.87 ± 0.09	9	--
	After single	0.89 ± 0.11	15	0.86 ± 0.11	15	0.38			--
	After multiple	0.86 ± 0.12	15	0.90 ± 0.11	15	0.21	0.91 ± 0.07	10	0.07
SI sagittal Peak vertical force (%BW)	Before	0.92 ± 0.09	15	0.92 ± 0.09	15		0.95 ± 0.06	9	--
	After single	0.93 ± 0.09	15	0.93 ± 0.09	15	0.96			--
	After multiple	0.91 ± 0.10	15	0.94 ± 0.09	15	0.22	0.96 ± 0.06	10	0.52
SI transversefront Peak vertical force (%BW)	Before	1.64 ± 0.21	8	1.64 ± 0.24	8		1.67 ± 0.21	4	--
	After single	1.61 ± 0.23	8	1.63 ± 0.24	8	0.43			--
	After multiple	1.61 ± 0.19	8	1.61 ± 0.27	8	0.98	1.69 ± 0.31	4	0.05
SI transversehind Peak vertical force (%BW)	Before	0.57 ± 0.06	7	0.56 ± 0.07	7		0.55 ± 0.06	5	--
	After single	0.58 ± 0.06	7	0.56 ± 0.07	7	0.52			--
	After multiple	0.56 ± 0.06	7	0.57 ± 0.08	7	0.56	0.57 ± 0.06	6	0.98

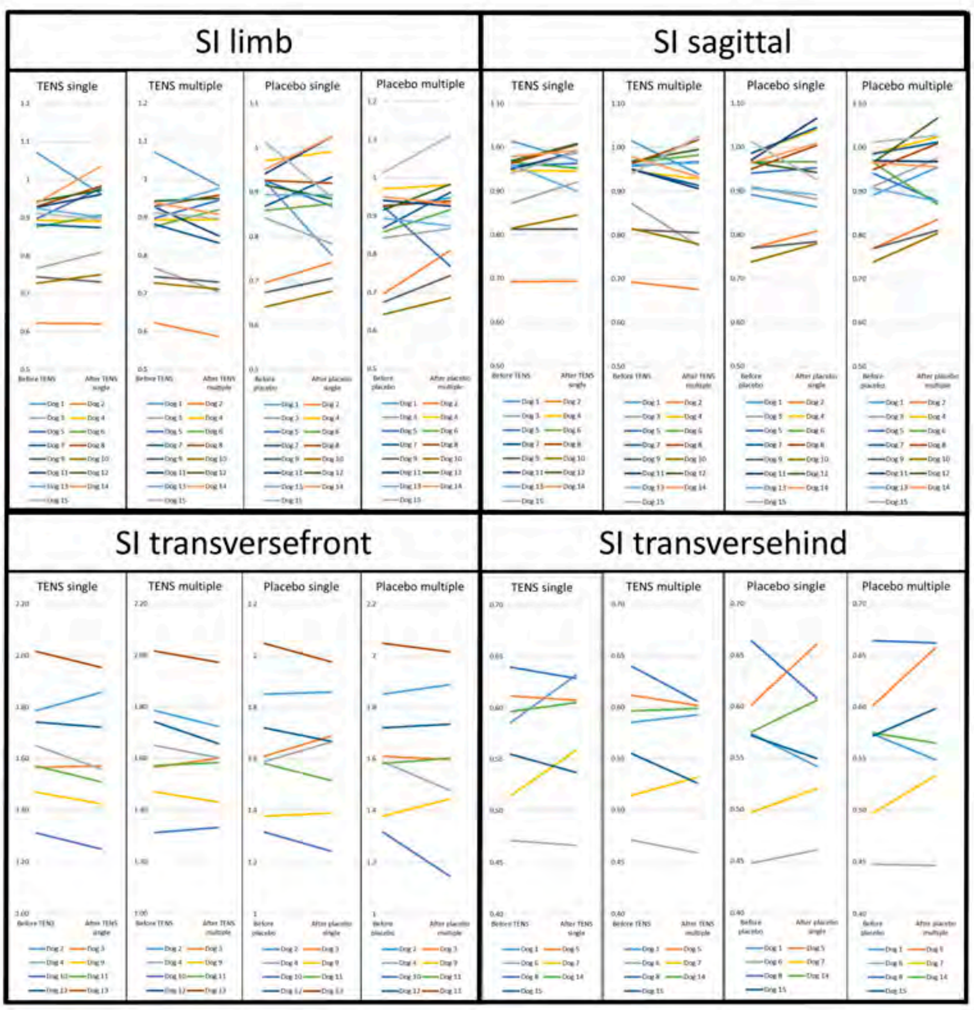

Figure 3. Individual symmetry indices of peak vertical force (%BW) for TENS and placebo. SI = symmetry index. SI_{limb} = lame limb/contralateral sound limb. $SI_{sagittal}$ = front and hind limb from lame body side/front and hind limb from sound body side. $SI_{transversefront}$ = front limbs from lame body half/hindlimbs from sound body half. $SI_{transversehind}$ = hindlimbs from lame body half/front limbs from sound body half. Single = single treatment. Multiple = multiple treatments. The suggested reference values are the following: SI_{limb} = 1.0, $SI_{sagittal}$ = 1.0, $SI_{transversefront}$ = 1.5, and $SI_{transversehind}$ = 0.66.

4. Discussion

Our results show no significant differences in peak vertical force (%BW), vertical impulse (%BW*sec), or SIs of osteoarthritic dogs when treated with TENS compared to placebo. Nor were there any significant differences in temporospatial parameters, such as stance time, swing time, stride time and stride length. Accordingly, our null hypothesis was accepted for this study protocol and population.

Our result differs from the only previous study on TENS as a stand-alone treatment for OA in dogs, where five dogs significantly increased weight bearing on the affected limb, evaluated by a force plate, indicating a positive pain-relieving effect of TENS [42]. The dogs were treated with a single treatment, at 70 Hz for 20 min, and the largest increase in weight bearing on the affected limb was seen immediately post-treatment and with changes remaining up to 180 min [42]. Similar to the Johnston et al. (2002) study, our measurements after a single treatment were made within an hour post-treatment [42]. Thus, the results from the present study are not in accordance with the Johnston et al. (2002) study nor with human studies indicating a pain-relieving effect during and shortly after TENS treatment [30,42].

The present study called for dog owners with a large commitment since it required a high degree of involvement from the owners, which narrowed the availability of possible candidates. Still, the study population in the present study was larger than in the previous study. It consisted of dogs with various locations of arthritic joints, thus representing the diverse patient population with OA. However, the five dogs in the Johnston study (2002) had OA in the stifle and the fifteen from our study in various joints, which may have had an effect on the lameness pattern and thus the inconsistent results [42,53,83].

Even though there are similarities in study design between previously conducted studies and the present study, there are also differences. A cross-over design was used to study the effect of the TENS and placebo interventions. This design entails a higher power and more statistical efficiency than the parallel design without control groups that have been used in previous studies on TENS in dogs [40,42,84]. An additional difference between our study and the previous ones was that two dogs were treated with NSAIDs throughout the TENS and placebo intervention. This was accounted for in the statistical analysis, with concurring NSAID treatment set as a fixed effect, and should not have affected the results significantly.

Our treatment sessions were longer than the treatment in the studies by Johnston et al. (2002) (20 min), Mlacnik et al. (2006) (15 min) and Krstić et al. (2010) (15 min) [40–42]. The decision to have a longer treatment session was based on clinical experience and from studies on humans, indicating, for example, an optimal treatment length of 40 min in knee OA [32,33,37,85]. In our study, a frequency of 80 Hz was used, a setting in between the frequency used in the studies by Krstić et al. (2010) (85 Hz) and Johnston et al. (2002) (70 Hz) [40,42]. A low degree of consistency in treatment settings was highlighted as one major limitation of TENS-related studies in a systematic review by Gibson et al. (2019) and Hyytiäinen et al. (2023) [37,43]. Therefore, our study aimed to have similar settings for frequency as the previous studies in dogs, and 80 Hz was used [37,40,42]. Further, the use of the strongest comfortable intensity possible is critical for pain relief with TENS; therefore, the intensity in the present study was increased until muscular fasciculation occurred as long as the dogs would withstand it [24,37]. Also, increasing intensity during the treatment compared to keeping the intensity fixed has been shown to decrease analgesic tolerance after five days in rats [38]. Since our study lasted longer than five days, the intensity was increased during treatment. As recommended by the literature, the most common electrode placement in our study was at the painful site; however, in one dog, this was not possible due to a limited area for electrode placement [25,86,87]. A transferred analgesic effect has been shown to happen in humans, and therefore, the placement over proximal nerve bundles is regarded as a suitable electrode location [88].

High-frequency TENS is claimed to alleviate pain through the pain gate theory and endogenic opioid release [24,38,39,89,90]. Studies on other pain-relieving treatments of dogs with OA have used changes in PVF and/or VI as outcome measures, evaluated with kinetic techniques [44,45,67–72,75]. Thus, therapeutic effects have been evaluated as an increase in weight on the affected limb and as a redistribution of weight to other limbs [59,60,74,75,91]. Measurement of ground reaction forces with a pressure-sensitive mat technique is an objective method for detecting asymmetries in weight distribution and takes all four limbs into consideration by using SIs [50,58,63,83,92–96]. In a previous study, when measuring 115 lame dogs on a pressure-sensitive mat, a specificity of 84.6% and a sensitivity of 91.1% were determined [50]. However, whether the technique can be used in the diagnosis of OA in dogs is discussed since studies have shown an overlap in the values for ground reaction forces of sound dogs and dogs with OA [58]. Further, there are several suggested cut-off values for the distinction between lame and not lame, indicating the difficulties in using the technique for the determination of a diagnosis [58,63,97,98]. The kinetic registrations in the present study were used to detect eventual changes in gait parameters within an individual dog and not for diagnosing OA; therefore, no cut-off values have been used.

Peak vertical force is considered an accurate variable for detecting weight distribution between limbs and is often used together with vertical impulse in gait analysis [56,58,63]. Peak vertical force and vertical impulse have been shown to be consistent in dogs with OA over time. Over two months, a change of 5% in these values is unusual, and a change of 10% is rare. Therefore, an effective treatment for OA could be expected to provide more than a 5% change in PVF and VI, which was not the case for TENS treatment compared to placebo in our study [56,68,99]. Besides ground reaction forces, temporospatial parameters such as stance time, swing time, stride time and stride length may be used to evaluate lameness; however, the documentation is limited [58,92,100]. The temporospatial parameters were included in the present study as the data can form a basis for future research in the area.

In the present study, some of the dogs had OA in multiple joints of multiple limbs. In these cases, the most affected limb (i.e., lame limb) was determined based on clinical history, clinical examination and kinetic data as in the studies by Moreu et al. (2003), Madore et al. (2007) and Roush et al. (2010) [83,101,102]. However, the involvement of multiple locations of OA could have influenced the results based on the reasoning that the dog would not shift as much of its weight from the affected limb to other limbs as if there was a single joint involvement [103–105]. However, in our study, gait parameters for all limbs and SIs were analysed, which most likely would have detected a difference in the exerted pressure on the ground from any limb based on the sensitivity of the pressure-sensitive mat [41,58,71,104]. The SIs in the present study are indices comparing the PVF between limbs and, thus, less vulnerable to the influence of velocity than solely reported PVF data, with SI sagittal showing a low variability of 2–3% in sound dogs [56,95,106]. The use of SIs to complement other parameters is becoming more common [41,56,61]. There is an increasing body of evidence from equine studies and some from canine regarding the influence on weight distribution and motion symmetry from compensatory lameness [74,91,100,103,107–109]. Thus, the reasons behind the inclusion of additional SIs, SI transverse and SI ipsilateral, were twofold: first, to get a better picture of eventual changes in the weight distribution between all four limbs, and second, to supply information for further research in the area. Based on the SIs, the results from the present study are not indicative of a TENS treatment effect different from that of a placebo.

As previously stated, velocity has a major effect on all gait parameters except for the SIs [110]. Therefore, the velocity was set as a fixed effect in the analysis for the TENS and placebo's effects on the gait parameters, with the exception of SIs. Furthermore, a fixed velocity interval was specifically used for the selection of trials [56,111]. Three trials were included for each measurement occasion, which is considered the gold standard, and this was possible most of the time [56]. In the three remaining occasions, the registrations were cancelled after two valid trials due to the risk of deterioration in lameness [56,112]. It is unlikely that the lack of three missing trials out of over three hundred had any major influence on the results. Mickelson et al. (2017) showed a mild alteration in weight bearing with repeated measurements in 61 dogs with mild to moderate lameness; the variance was <5% [112]. Therefore, in our study, the three missing trials should not have influenced our results drastically.

The handler may affect the outcome of the pressure-sensitive mat measurements by his placement in relation to the dog and through his general behaviour [113,114]. In the present study, the majority of trials had the same handler and leash side. According to Jevens et al. (1993), a variation between 0 and 7% of the total variance in gait parameters is to be expected when changing handlers [113]. However, due to the small portion of measurements that was affected by the change of handler and side, this should not have influenced the results significantly.

All the dogs included in the present study had OA and pain from the musculoskeletal system as determined by clinical history and clinical examinations. Medication with NSAID is used as the gold standard when investigating the effects of new pain-relieving treatments [115]. The NSAID intervention, i.e., study part 2, was performed to test whether a standard pain relief medication would change the gait parameters of the dogs. No significant differences were seen before and after NSAID treatment for stance time, swing time, stride time, stride length, and peak vertical force (%BW). However, the results show a significant increase in vertical impulse (%BW*sec) for the ipsilateral leg ($p = 0.02$) after treatment with NSAID. Previous studies on weight redistribution have not shown an isolated increase in VI for the ipsilateral leg without any other changes in gait parameters for the other limbs [74,100,107]. Our result is, therefore, not consistent with the current documentation on weigh redistribution in lame dogs and can, therefore, be suspected to be a false positive value. Firocoxib has an indication for pain relief in OA, with the dosage per kg body weight given in the study; however, the length of the treatment for sufficient pain relief is not specified [82]. The treatment period might have been too short to ensure increased efficacy in dogs with chronic pain [21,116,117]. It is also possible that the discrete change in VI (%BW) is explained by the time (12–24 h) between the last medication and the measurement occasion [82]. Further, in a study by Rhodin et al. (2017), horses with lameness did not change their gait pattern in response to NSAID treatment; however, after diagnostic anaesthesia, the lameness improved, so the minor response in the present study may also be due to the insufficient treatment effect of the NSAID [118].

In both veterinary and human medicine, the evidence of the effect of TENS on chronic pain is inconclusive, reported in systematic reviews [35,37,43,119–121]. The major deficits in the scientific material are small studies of low quality and a large variety of settings used for the TENS treatment. Future studies in veterinary medicine should, therefore, ensure similar treatment protocols and study designs to be used to increase the level of evidence.

5. Conclusions

To the author's knowledge, our study is one of the few that measures the effect of TENS treatment in dogs with OA. The results of our study provide preliminary evidence that TENS, with the settings used, did not cause significant changes in gait parameters in dogs with OA. Thus, the null hypothesis that TENS treatment of dogs with OA will not change gait parameters differently than placebo treatment was accepted. However, further studies are needed to confirm the clinical efficiency of TENS as a treatment for OA in dogs.

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Informed Consent Statement: Informed consent was obtained from all subjects (owners of the animals) involved in the study.

Data Availability Statement: The datasets presented in this article are not readily available because the data are part of an ongoing study. Requests to access the datasets should be directed to anja.pedersen@slu.se.

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RESEARCH ARTICLE

Effect of bar jump height on kinetics and kinematics of take-off in agility dogs

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Data Availability Statement: The data underlying the results presented in the study are available from https://doi.org/10.23729/cac13e49-17cf-40b3-b556-e741d82126e3 Details on the descriptives of the dogs (e.g. height and age) cannot be shared publicly to protect privacy, as it could be used to identify participants. These details on the dogs serve only to describe the sample and do not impact the study's primary analysis. Descriptive data on the dogs is available upon reasonable request via email at leena.inkila@helsinki.fi.

Abstract

Sport-related injuries have been reported to occur in around one-third of agility dogs. Higher bar height in competitions has been shown to increase odds of an injury. This study evaluated the effect of bar height on the kinetics and kinematics at take-off to a bar jump. Forces from fore- and hindlimb pairs were measured with force plates. A three-dimensional motion capture system was used to measure sagittal joint kinematics of the shoulder, elbow, carpus, hip, stifle, and tarsal joints, as well as limb coordination, trunk horizontal velocity, take-off distance, and take-off angle. Data were collected for 17 Border Collies at three different bar heights: 80%, 100%, and 120% of wither height. A linear mixed model was used for statistical analysis. At higher bar height, decelerative impulses were greater and accelerative impulses decreased along with greater vertical impulses from forelimb and hindlimb pairs ($p<0.001$). Post-hoc analyses revealed differences between all three bar heights ($p<0.01$), except for forelimb decelerative impulse, which did not differ between 80% and 100% heights. Sagittal range of motion was greater, through increased peak flexion or extension, at 120% bar height than at lower bar heights ($p<0.05$) in almost all measured limb joints. The only exceptions were leading forelimb shoulder and elbow joints and leading hindlimb hip joint. With increasing bar height, the horizontal velocity of trunk decreased ($p<0.001$), and take-off angle became steeper ($p<0.001$), with all bar heights differing from each other ($p<0.01$). Temporal synchronicity between trailing and leading limbs increased and cranio-caudal distance decreased in forelimbs ($p<0.05$) and hindlimbs ($p<0.01$) as bar height increased. Increased vertical and decelerative impulses, as well as the greater peak flexion and extension angles of joints, may indicate greater load on the tissues at higher bar heights, which could explain the increased odds of injury at higher bar heights in agility dogs.

Introduction

Approximately one-third of agility dogs suffer a sport-related injury during their sport career [1–3], with the bar jump, A-frame, and dog walk being the obstacles most often associated

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with injuries [1,2,4,5]. Moreover, bar jumps are the most common obstacle on agility courses [1]. Thus, the highly frequent exposure and the reported association with injuries make bar jumps an important factor to consider in relation to agility dogs' safety and welfare.

In agility, dogs are divided into four height categories based on their wither height according to the Fédération Cynologique Internationale (FCI) regulations: small (wither height < 35 cm), medium (35 cm to <43 cm), intermediate (43 cm to <48 cm), and large (≥48 cm) [6]. In Europe, larger dogs jump typically higher bar heights in relation to their wither height (up to 125% of wither height) than most smaller dogs (as low as 72% of wither height) [6,7]. In one study, the odds ratio for musculoskeletal injury was increased in agility dogs who jump obstacles at least five centimeters above their wither height relative to dogs jumping proportionally lower heights [8], although another study did not observe this association [2].

Bar height is a highly debated subject in the sport of agility. In 2018, the maximum bar height of the jump obstacles in all dog height categories was reduced by five centimeters according to the renewed international FCI regulations [9]. For example, the maximum bar height of the "large" category was reduced from 65 cm to 60 cm. In addition, a new, fourth dog height category, "intermediate", was introduced to FCI regulations in 2023 to reduce bar heights for some dogs who used to compete in the "large" category [6]. Similar rule changes of reducing bar heights and adding height categories have been made to national agility regulations in Europe as well as in agility organizations in the United States [10–12]. Nevertheless, even after the regulation changes, the dogs in the lower end of wither height range in all international height categories still jump at least five centimeters above their wither height [6]. Currently, the decisions for the above-mentioned regulation changes have been based on the sparse scientific evidence as well as anecdotal evidence.

Research on the effect of bar height on joint kinematics at take-off is limited. With increasing bar height, it is known that extension of the tarsus and flexion of the shoulder and elbow joints increase as dogs' hindlimbs are about to leave the ground [13]. However, previous studies have evaluated joint angles only from still images at one or two time points of take-off [13,14]. Thus, the full range of motion (ROM) and maximum flexion or extension angles during take-off are unknown. Greater vertical velocity is required at take-off to increase the height of the jump [15]. Additionally, higher bar height is associated with decreased horizontal velocity during the flight phase in agility dogs [14]. To our knowledge, neither the approach velocity nor the possible deceleration during the stance phases of take-off during different jump heights have been evaluated.

The roles of fore- and hindlimbs appear to be different at take-off. Roughly 55% of the vertical impulse at take-off is produced by the forelimbs when bar height is 90% of the dogs' wither height [16]. Forelimbs produce mainly decelerative impulse during take-off, whereas the net impulse from hindlimbs is accelerative [16]. Forelimbs are spatially and temporally further away from each other, whereas hindlimbs take-off more synchronously [16]. No studies exist on how bar height affects kinetics or limb synchronicity at take-off.

The overall aim of this study was to examine the effect of bar height on jumping biomechanics at take-off in intermediate and large agility dogs. The focus was the effect of bar jump height on ground reaction forces (GRFs) and sagittal plane kinematics during the stance phase at take-off. Additionally, limb coordination, horizontal velocity, take-off distance, and take-off angle in relation to bar height were evaluated to provide a more complete understanding of jump performance. We hypothesized that an increase in bar height would lead to increased hip and stifle flexion during take-off, and therefore, greater ROM in both joints. We expected the vertical and decelerative impulses exerted on hindlimbs to increase with bar height. Additionally, the take-off angle was expected to be steeper and horizontal velocity at lift-off slower as bar height increases.

Materials and methods

The study design was approved by the Viikki Campus Research Ethics Committee (statement 10/2019). Dog owners were given written and oral information about the study, and they provided signed consent for participation of their dog.

Animals

Border Collies competing in agility at different levels were included in the study. Participants were recruited through social media and local agility clubs. Dogs were excluded if they had had an injury or illness causing a break from agility in the past two months prior to data collection. Prior to the jump-related measurements, a veterinary orthopedic surgeon (JM) conducted physical and orthopedic examinations on all dogs. Dogs were excluded if they were not considered fit to perform (e.g. heart murmur, lameness, painful reactions during manipulation of joints).

Power analysis, based on mean values and standard deviations of joint angles at two phases of take-off at two bar heights (93% and 151% of wither height) reported by Birch & Lesniak (2013) (13), showed that 25 dogs would be a sufficient sample size to reveal significant differences (alpha: 0.05, power: 0.8) in joint angles of the shoulder, elbow, stifle, and tarsus between bar heights.

Experimental setup

After the physical and orthopedic examinations, measurement of body mass (kg) and wither height (cm) took place. Reflective markers (diameter 9.5 mm) were attached to anatomical landmarks presented in Fig 1 (adapted from [17]). The skin was shaved at the marker sites and markers attached with double-sided tape. The markers on the limbs were additionally fixed with kinesiology tape (Sensiplast, Delta-Sport Handelskontor, Hamburg, Germany).

Dogs performed bar jumps at three bar heights: at 80%, 100%, and 120% of their wither height. These bar heights correspond to the variability in proportional bar heights in current international competition rules. The order of the bar heights was block randomized: there were six possible orders, each of which occurred once in the block of six dogs [18].

Each trial consisted of three consecutive bar jumps of the same height on a straight line with six-meter distances between jumps to achieve course-like speed and striding. Since the order effect may cause kinematic and kinetic differences in the sequence of three jumps, only the take-off of the second jump was measured, representing a course situation with an obstacle before and after each jump. The start line was set five meters before the first jump. A toy or food reward was placed five meters after last jump to ensure the dog's direction of movement, encouraging it to remain on a straight path throughout the performance. The handler left the dog to wait in the start point and moved past the last jump before releasing the dog with a verbal cue. The handler was instructed to maintain consistent handling throughout all trials. Prior to data collection, handlers were informed about the jump sequence and their dogs' bar heights and instructed to familiarize their dog with those before the measurements.

A marker-based 3D motion capture system (Vicon Motion Systems, Oxford, UK) consisting of 15 cameras (Vero v2.2) with a sampling frequency of 200 Hz was used. Five force plates (models BP60001200-4K and BP9000900-4K, AMTI Inc, Watertown, MA, USA) placed sequentially without gaps (total area covered 0.6 m * 5.7 m) simultaneously recorded the horizontal and vertical ground reaction forces during take-off at 1 KHz. The surface, including the force plates, was a non-slippery tartan track (3M, St. Paul, MN, USA).

For a valid trial, the dog had to clear all three jumps without visually apparent deviation from the straight line. The aim was to record three valid trials at each bar height with

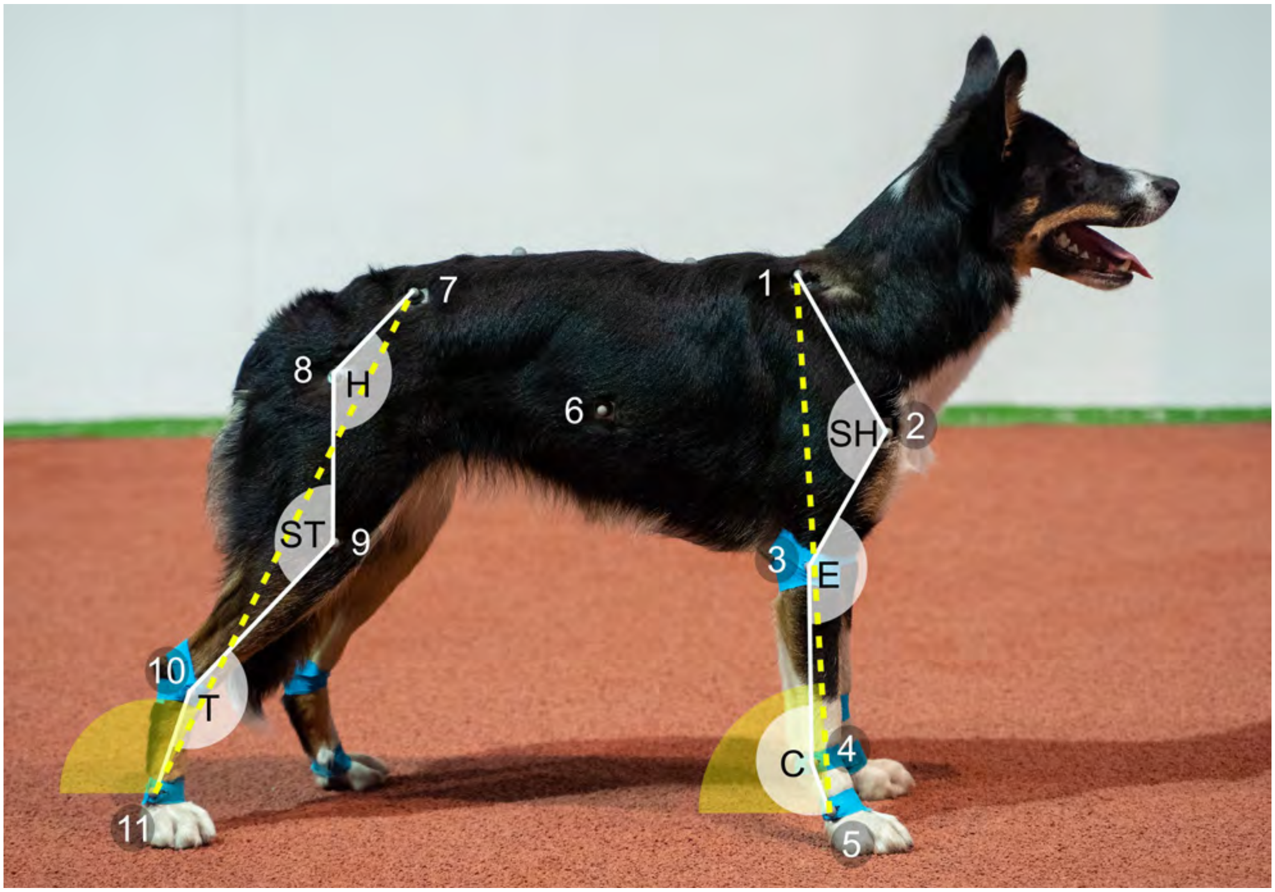

Fig 1. Placement of reflective markers and calculated sagittal joint angles. The markers shown in the image were used to calculate the marked joint angles during stance phases of each limb in take-off. 1 = dorsal border of scapula, 2 = greater tubercle of humerus, 3 = lateral humeral epicondyle, 4 = ulnar styloid process, 5 = distal end of fifth metacarpal, 6 = over the 11th rib at the level of the shoulder joint, 7 = cranial dorsal iliac spine, 8 = greater trochanter of femur, 9 = lateral femoral epicondyle, 10 = lateral malleolus of fibula, 11 = distal end of fifth metatarsal. SH = shoulder, E = elbow, C = carpus, H = hip, ST = stifle, T = tarsus. Dashed yellow line marks the line used for limb angle calculation.

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kinematic data recorded of all markers and force plate data of all four limbs. Kinetics were measured only if all paws took off from the force plates. After each trial, contact with the force plate was confirmed from force-plate data and slow-motion video recorded by a mobile phone (OnePlus 5T, OnePlus Technology, Shenzhen, China) at 60 Hz. All valid trials were included in the analysis even if data was missing for some variables (e.g. kinematic data from all markers, but no kinetic data due to dog not properly contacting force plates). Thus, more than three trials per height were included from some dogs. The unbalanced number of trials per height per dog was accounted for in statistical analysis.

Processing of kinematic and gait variables

A 4th-order low-pass Butterworth filter was used on raw marker trajectories (20 Hz) and on the force plate data (150 Hz). Cut-off frequencies were based on evaluation of periodograms. The Cartesian coordinate system had the y-axis positive in the direction of travel, z-axis positive upwards, and x-axis positive towards the dog's right.

We measured the stance phase of each limb before the aerial phase leading the dog over the obstacle. Touch-down (TD) and lift-off (LO) timings (beginning and end of the stance phase) were recorded for each limb. Force plate data alone were insufficient to determine TD and LO timings if multiple paws contacted the force plate simultaneously. Thus, a combination of force plate data, coordinates of markers on the 5th metacarpal and metatarsal bones, and 3D visualization was used. All recordings were processed by the same person (LI) with excellent intra-rater reliability: intraclass correlation coefficient (two-way mixed effects absolute agreement) was 0.988 (95% confidence interval 0.95–1.00) for forelimb events and 0.998 (95% confidence interval 0.99–1.00) for hindlimb events. During take-off, in gallop, the dogs' limbs were defined according to their order of contact with the ground as follows: trailing forelimb (TrFL), leading forelimb (LeFL), trailing hindlimb (TrHL), and leading hindlimb (LeHL). If, at take-off, the hindlimbs of the dogs touched the ground exactly at the same time, the hindlimb on the side of the leading forelimb was marked as the trailing hindlimb to allow for comparison with other trials. This approach was chosen as the dogs used a rotary gallop stride pattern in most of the trials, and thus, the leading forelimb and trailing hindlimb were typically ipsilateral.

Sagittal joint angles (i.e. intersegmental angle) were calculated from marker trajectory data using a custom-made 2D kinematic model with Vicon ProCalc software (Vicon Motion Systems, Oxford, UK). The sagittal plane was defined as the plane created by y- (craniocaudal) and z-axes (vertical). Sagittal ROM, maximum flexion, and extension angles were calculated for shoulder, elbow, carpal, hip, stifle, and tarsal joints of trailing and leading fore- and hindlimbs (Fig 1). Joint angles were evaluated throughout the stance phase. To track the movement of the trunk, the kinematic model included a virtual marker 'Trunk', which was created midway between the two reflective markers on the sides of the trunk. Additional kinematic variables are listed in Table 1. Each kinematic variable was calculated only if the marker data required for that variable were available. If the marker had fallen off or was poorly visible to the cameras, variables calculated using that marker were not recorded.

Processing of kinetic variables

Vertical and craniocaudal mean forces, peak forces, and impulses were calculated from the force plate data (Fig 2). Force-related values were normalized to body weight (BW). Thus, the unit of force becomes BW and of impulse BWs. The combined force data was used from forelimb pair and hindlimb pair, as the size and placement of the force plates did not allow measurement of individual limb forces. Additionally, vertical and net cranio-caudal impulses were calculated for all four limbs (fore- and hindlimbs combined). Weight distribution was calculated as the proportion of total vertical impulse produced by forelimbs. The direction of the resultant force vector relative to horizontal was calculated from mean vertical and mean craniocaudal forces.

If the leading forelimb and trailing hindlimb simultaneously contacted the same force plate, their force curves overlapped. The magnitude of overlap was assessed by the value of vertical force at the cut-off point. To estimate fore- and hindlimb impulses from these trials, the lowest vertical force value was used as a cut-off; force values before the cut-off timing were used to calculate forelimb impulses and values after the cut-off timing to calculate hindlimb impulses (S1 Fig). To evaluate whether this produced error in calculated impulse values, artificial overlapping versions were created from trials with no overlap and fore- and hindlimb kinetic data available. Twenty artificial versions with increasing overlap were created from each trial (range of overlap magnitude 0.002–2.031 BW). From the artificial overlap versions, the error in the impulse values was calculated by comparing true impulse values from the actual data with no overlap to predicted impulse values from the artificial versions with varying degree of overlap.

The preliminary effect of bar height on impulse values was evaluated from trials without overlap using the same statistical methods as in the final analyses (see Statistical analyses). The

Table 1. Description of kinematic variables measured during take-off to a jump.

Variable	Description
Joint peak flexion [a]	Minimum sagittal joint angle during stance.
Joint peak extension [a]	Maximum sagittal joint angle during stance.
Joint ROM [a]	Range of motion during stance.
Take-off distance	Distance between jump obstacle and LeHL at TD.
Trunk angle at lift-off	Angle of dog's trunk, measured from between shoulders to between hips, at LO of LeHL. Relative to horizontal plane.
Take-off angle	Virtual trunk marker's direction of travel during first 50 ms of the aerial phase, relative to horizontal plane.
Trunk height at TrFL TD	Height of virtual trunk marker, relative to ground, at touch-down of trailing forelimb. Normalized to dog's wither height.
Trunk height at apex	Highest point of virtual trunk marker, relative to ground, during aerial phase. Value was calculated from vertical velocity immediately after LeHL left the ground. Normalized to dog's wither height.
Bar clearance	Bar height subtracted from trunk height at the apex. Normalized to dog's wither height.
Horizontal velocity at approach	Horizontal velocity of virtual trunk marker before TD of TrFL.
Horizontal velocity after LO	Horizontal velocity of virtual trunk marker after LO of LeHL.
Stance time [b]	Duration of ground contact.
Synchronicity of FLs/HLs	Calculated as time between TD of trailing and leading limbs. Value recorded as percentage of trailing limb stance time [16].
Craniocaudal distance between FLs/HLs	Distance between trailing and leading limbs at TD in y-direction.
Craniocaudal distance between LeFL and TrHL	Distance between LeFL and TrHL at TD in y-direction.
Mediolateral distance between FLs/HLs	Distance between trailing and leading limbs at TD in x-direction.
Craniocaudal distance between HL and trunk marker	Distance between hindlimb paw and virtual trunk marker at TD in y-direction. Positive values indicate paw being caudal to the trunk marker.
Limb angle at TD [b]	Angle between the ground and the line from dorsal scapula to distal metacarpal bone in FLs or the line from greater trochanter to distal metatarsal bone in HLs in sagittal plane measured at TD of each limb (Fig 1).
Limb angle at LO [b]	As 'Limb angle at TD' but measured at LO.
Stride number	Number of strides before take-off (between jumps 1 and 2).

ROM = range of motion, TrFL = trailing forelimb, LeFL = leading forelimb, TrHL = trailing hindlimb, LeHL = leading hindlimb, TD = touch-down of a limb, LO = lift-off of a limb.

[a] Joint angles were calculated for shoulder, elbow, carpus, hip, stifle, and tarsal joints with separate values for trailing and leading limbs.

[b] Separate values for TrFL, LeFL, TrHL, and LeHL.

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smallest expected difference in impulse values between two bar heights with $p<0.1$ was used for evaluations for each impulse variable. This p-value was chosen to ensure that we evaluated effect of overlap on all variables that might be affected by bar height. Absolute errors below 30% of the expected effect were considered acceptable. The artificial data with overlap magnitude below 0.4 BW (632 artificial trials) had a median overlap of 0.23 BW (interquartile range 0.14–0.32 BW). From all artificial trials with overlap magnitude below 0.4 BW, absolute errors in impulse values were always below 30% of the expected bar height effect for all impulse variables. Mean absolute errors ranged from 0.1% to 5.4% of the expected bar height effect depending on the impulse variable. Thus, we consider the chosen threshold as a good trade-off

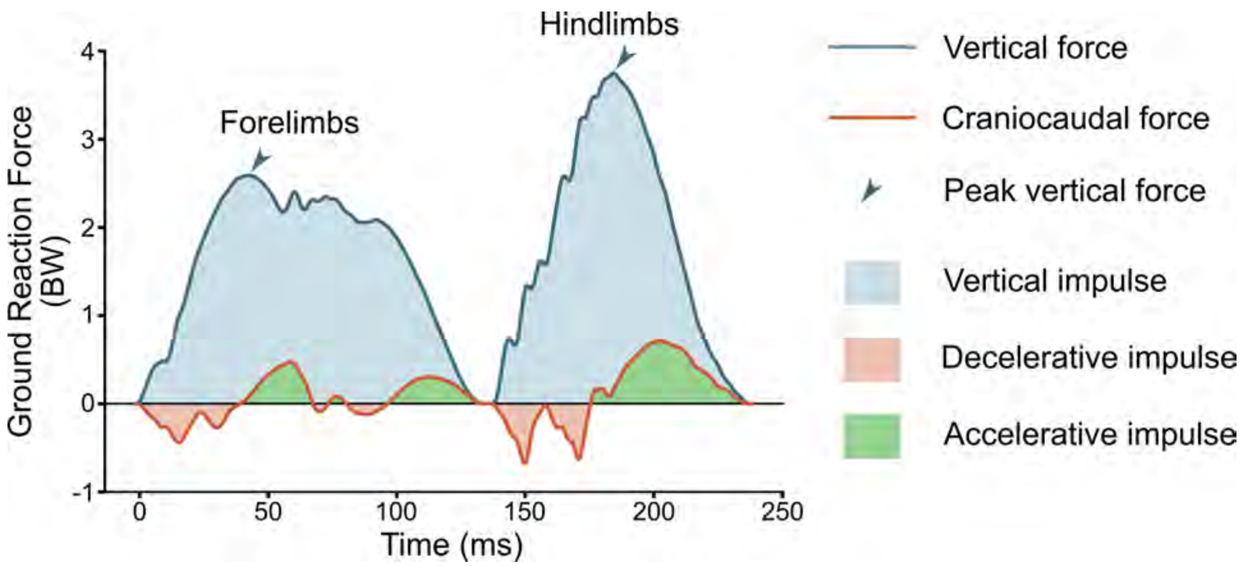

Fig 2. Calculation of peak force and impulse values from force plate data. Peak force and impulse values were calculated separately for fore- and hindlimbs. If trailing and leading limbs contacted separate force plates, force values from the two plates were summed. In this example of individual trial at 100% of wither height, the force curves from fore- and hindlimbs do not overlap, as there had been a suspension phase between fore- and hindlimbs. An example with overlap is presented in S1 Fig.

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between the number of acceptable trials and error generated by our method to deal with overlap.

Impulses, mean force values, and impulse distributions for fore- and hindlimbs were discarded from trials where overlap was above 0.4 BW, and only combined impulses for all four limbs were recorded from these trials. Peak force values from these trials were not discarded, as they were not affected by the overlap issue. The same cut-off method was used if the leading hindlimb of the approach stride was simultaneously on the same force plate with the trailing forelimb of the take-off stride. If overlap magnitude was above 0.4 BW, the forelimb impulses and mean force values were discarded along with impulse distributions and combined impulse values for all four limbs.

Statistical analysis

Descriptive statistics are presented as mean ± standard deviation (SD). The association between 'Stride number' and 'Bar height' was analyzed with Chi-squared test. A linear mixed model with an unstructured correlation structure, identity link function, and normal distribution was used to evaluate the effect of 'Bar height' on previously described kinetic and kinematic variables. Preliminary evaluation showed associations between 'Stride number' and dependent variables, leading to its inclusion in the model. Experience of the dog, evaluated as combination of training years and competition class, has been shown to affect jumping biomechanics in agility dogs [16]. However, adding competition class to the model did not improve it for most of the dependent variables based on the Akaike Information Criterion. Thus, competition class was not included in the final model. The model had bar height and stride number as fixed effects, and the dog ID as a random effect. Significance was set at $p<0.05$.

Analyses were conducted in R version 4.2.2 (R Core Team) using lmer function from lmerTest package (Kuznetsova et al., 2017). The model was fitted using restricted maximum likelihood estimation and Kenward-Roger method for degrees of freedom. Normality of the residuals was confirmed with evaluation of QQ-plots. Lack of multicollinearity between 'Bar height' and 'Stride number' was confirmed with variance inflation factor (VIF). Post-hoc pairwise comparisons for 'Bar height' and estimated marginal means with standard deviations were run using "emmeans" package. Intraclass coefficient (ICC, i.e. subject variance divided by subject plus residual variance) was calculated for each dependent variable to verify the percentage of the total variance that was explained by the dog ID.

Results

Twenty-six Border Collies were recruited from whom eight dropped out prior to data collection, mainly due to owner-reported injuries of dogs. Of the 18 dogs participating to data collection, one was excluded during orthopedic examination, leaving a final sample of 17 dogs.

Of the 17 dogs, eight were females and nine males. Mean ± standard deviation for age was 4.2 ± 2.1 years and for wither height 51.8 ± 3.2 cm. Nine dogs competed in the lowest class 1, four in class 2, and four in the highest class 3.

A total of 176 trials were included in the analysis: 56 trials with jump bar at 80%, 63 trials at 100% and 57 trials at 120% of wither height. The mean number of analyzed trials per bar height per dog was 3.5 ± 1.4 (range 0–7). Except for two dogs, all dogs had minimum of three analyzed trials on all three bar heights. One dog had only one trial at one bar height, while another dog had minimum of three trials at two bar heights. Twelve trials from eight dogs were excluded because the dog knocked off a bar in the trial sequence; of these trials, 11 (92%) were at 120% bar height and one (8%) at 80% bar height.

The simultaneous contact of the leading forelimb and trailing hindlimb on a force plate resulted in overlapping force curves in 55 trials. In eight of these trials, the overlap magnitude was $\geq$ 0.4 BW, leading to exclusion of fore- and hindlimb impulses, mean force values, and impulse distributions. Additionally, in 18 trials the leading hindlimb of approach stride overlapped with the trailing forelimb of take-off stride. From five trials with overlap magnitude $\geq$ 0.4 BW, the following variables were excluded: forelimb impulses and mean force values as well as impulse distributions and combined impulse values from all four limbs.

Full results of the linear mixed model for the fixed effects of bar height and stride number as well as the pairwise comparisons are presented in Tables 2–4 and S1–S6.

Effect of bar height on peak and mean forces at take-off

Bar height affected peak and mean forces exerted on fore- and hindlimbs (Table 2). In fore- and hindlimbs, there was a main effect of bar height for mean and peak vertical forces ($p<0.001$). Furthermore, the post-hoc analysis revealed that all bar heights differed from each other ($p<0.001$ for all pairwise comparisons). In forelimbs, the estimated differences between 80% and 120% heights were a 0.19 BW (body weight) increase in mean vertical force and a 0.56 BW increase in peak vertical force. In hindlimbs, the estimated differences between 80% and 120% heights were a 0.30 BW increase in mean vertical force and a 0.30 BW increase in peak vertical force.

Bar height affected mean craniocaudal force of the fore- and hindlimbs ($p<0.001$), with significant differences between all bar heights in both limb pairs ($p<0.001$). The estimated difference in mean craniocaudal force between 80% and 120% heights was -0.13 BW in forelimbs and -0.10 BW in hindlimbs. In both fore- and hindlimbs, the direction of the resultant force vector was affected by bar height ($p<0.001$), with all heights differing from each other ($p<0.001$ for all pairs). The estimated difference between 80% and 120% heights was -4.0° in forelimbs and -3.4° in hindlimbs, indicating a more backward-oriented direction of the force vector at 120% height.

Table 2. Linear mixed model results: Effect of bar height and approach stride number on kinetics at take-off to a jump in agility dogs.

Variable		Main effects				Estimated marginal mean ± SE			ICC
		Bar height		Stride number		Bar height:			
	n	p-value	Difference	p-value	Difference	80%	100%	120%	%
Forelimbs									
Mean vertical force (BW)	158	<0.001	80<100<120	<0.001	2<1	1.71 ± 0.03	1.79 ± 0.03	1.89 ± 0.03	73
Mean craniocaudal force (BW)	158	<0.001	120<100<80	<0.001	2<1	0.01 ± 0.02	-0.02 ± 0.02	-0.12 ± 0.02	62
Peak vertical force (BW)	167	<0.001	80<100<120	0.980		2.79 ± 0.09	3.02 ± 0.09	3.35 ± 0.09	69
Vertical impulse (BWs)	158	<0.001	80<100<120	<0.001	2<1	0.207 ± 0.005	0.216 ± 0.005	0.235 ± 0.005	66
Decelerative impulse (BWs)[a]	158	<0.001	120<80, 120<100	0.170		-0.012 ± 0.002	-0.014 ± 0.002	-0.022 ± 0.002	49
Accelerative impulse (BWs)	158	<0.001	120<100<80	<0.001	2<1	0.014 ± 0.001	0.011 ± 0.001	0.007 ± 0.001	50
Net craniocaudal impulse (BWs)	158	<0.001	120<100<80	<0.001	2<1	0.001 ± 0.002	-0.003 ± 0.002	-0.015 ± 0.002	58
Direction of resultant force vector (°)	158	<0.001	120<100<80	<0.001	2<1	90.4 ± 0.5	89.2 ± 0.5	86.4 ± 0.5	61
Hindlimbs									
Mean vertical force (BW)	163	<0.001	80<100<120	0.002	2<1	1.96 ± 0.05	2.06 ± 0.05	2.26 ± 0.05	73
Mean craniocaudal force (BW)	163	<0.001	120<100<80	<0.001	2<1	0.19 ± 0.02	0.14 ± 0.02	0.08 ± 0.02	75
Peak vertical force (BW)	171	<0.001	80<100<120	<0.001	2<1	3.53 ± 0.07	3.66 ± 0.07	3.82 ± 0.07	76
Vertical impulse (BWs)	163	<0.001	80<100<120	<0.001	2<1	0.182 ± 0.003	0.188 ± 0.003	0.207 ± 0.003	43
Decelerative impulse (BWs)[a]	163	<0.001	120<100<80	0.718		-0.009 ± 0.001	-0.011 ± 0.001	-0.014 ± 0.001	69
Accelerative impulse (BWs)	163	<0.001	120<100<80	<0.001	2<1	0.026 ± 0.001	0.023 ± 0.001	0.021 ± 0.001	63
Net craniocaudal impulse (BWs)	163	<0.001	120<100<80	<0.001	2<1	0.017 ± 0.002	0.012 ± 0.002	0.007 ± 0.002	68
Direction of resultant force vector (°)	163	<0.001	120<100<80	<0.001	2<1	95.4 ± 0.5	93.7 ± 0.5	92.0 ± 0.5	65
All four limbs									
Vertical impulse (BWs)	163	<0.001	80<100<120	<0.001	2<1	0.391 ± 0.007	0.405 ± 0.007	0.443 ± 0.007	59
Net craniocaudal impulse (BWs)	163	<0.001	120<100<80	<0.001	2<1	0.018 ± 0.003	0.008 ± 0.003	-0.008 ± 0.003	54
Weight distribution (% of vertical impulse on FLs)	156	0.340		0.011	2<1	53.0 ± 0.6	53.5 ± 0.6	53.2 ± 0.6	60

SE = standard error, ICC = intraclass correlation coefficient, BW = body weight, FLs = forelimbs.

Main effects for bar height and stride number are presented as p-values along with estimated marginal means for all bar heights. Different shade of orange background indicates significant difference (p<0.05) between bar heights. Darker background denotes greater force, acceleration, or deceleration. White background indicates no differences between bar heights. All p-values of pairwise comparison for bar height are presented in S1 Table. Estimated marginal means for stride numbers are presented in S2 Table.

[a] Lower values indicate greater deceleration.

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Effect of bar height on impulses at take-off

Impulse values in fore- and hindlimbs were affected by bar height (Table 2). There was a main effect of bar height on vertical impulse of fore- and hindlimbs ($p<0.001$), with differences emerging between all bar heights (80% vs. 100%, p = <0.001 in FLs and p = 0.008 in HLs, $p<0.001$ for other pairwise comparisons). The vertical impulse increased by an estimated 0.028 BWs in forelimbs and by 0.024 BWs in hindlimbs from 80% to 120% height.

Bar height affected the decelerative impulse of forelimbs ($p<0.001$), with post-hoc analyses showing greater deceleration as height increased (Fig 3); differences were between 80% and 120% heights (β = -0.010 BWs, $p<0.001$) and 100% and 120% heights (-0.009 BWs, $p<0.001$). The decelerative impulse of hindlimbs was affected by bar height ($p<0.001$), with all bar heights differing from each other in post-hoc analyses ($p<0.001$) (Fig 3). The estimated difference in decelerative impulse between 80% and 120% heights was -0.006 BWs. Bar height had an effect on accelerative impulse in fore- and hindlimbs ($p<0.001$), with all heights differing from each other ($p\leq0.001$ for all pairwise comparisons) (Fig 3). The estimated decrease in

Table 3. Linear mixed model results: Effect of bar height and approach stride number on jump arch and limb coordination at take-off in agility dogs.

Variable		Main effects				Estimated marginal mean ± SE			ICC
		Bar height		Stride number		Bar height:			
	n	p-value	Difference	p-value	Difference	80%	100%	120%	%
Horizontal velocity at approach (m/s)	161	<0.001	120<100<80	<0.001	2<1	7.27 ± 0.11	7.15 ± 0.11	6.86 ± 0.11	81
Horizontal velocity after lift-off (m/s)	173	<0.001	120<100<80	<0.001	2<1	7.29 ± 0.14	7.11 ± 0.14	6.60 ± 0.14	80
Take-off distance (cm)	174	0.012	120<80, 100<80	<0.001	2<1	192 ± 9	183 ± 9	183 ± 9	81
Trunk angle at lift-off (˚)	161	<0.001	80<100<120	0.001	2<1	15.0 ± 0.7	16.8 ± 0.7	20.9 ± 0.7	59
Take-off angle (˚)	154	<0.001	80<100<120	0.071		10.7 ± 0.6	12.9 ± 0.6	17.2 ± 0.5	61
Trunk height at TrFL touch-down (% of wither height)	162	<0.001	120<100<80	0.017	1<2	76.2 ± 0.7	75.1 ± 0.6	73.6 ± 0.6	69
Trunk height at the apex (% of wither height)	173	<0.001	80<100<120	<0.001	2<1	128.9 ± 3.2	141.8 ± 3.2	168.3 ± 3.2	71
Bar clearance (% of wither height)	173	<0.001	100<120, 100<80	<0.001	2<1	48.9 ± 3.2	41.8 ± 3.2	48.3 ± 3.2	71
Stance time									
Trailing forelimb (ms)	176	<0.001	80<120, 100<120	0.799		82 ± 3	84 ± 3	91 ± 3	83
Leading forelimb (ms)	176	<0.001	80<120, 100<120	<0.001	2<1	75 ± 2	77 ± 2	80 ± 2	71
Trailing hindlimb (ms)	176	<0.001	80<120, 100<120	0.525		79 ± 2	80 ± 2	84 ± 2	73
Leading hindlimb (ms)	176	<0.001	80<120, 100<120	0.778		74 ± 2	75 ± 2	80 ± 2	64
Synchronicity									
Forelimbs (% of TrFL stance time)[a]	176	<0.001	120<100<80	0.010	2<1	56.4 ± 1.9	54.2 ± 1.9	50.3 ± 1.9	58
Hindlimbs (% of TrHL stance time)[a]	176	<0.001	120<100<80	<0.001	2<1	22.7 ± 2.4	19.7 ± 2.4	13.1 ± 2.4	73
Distance between limbs at TD									
Craniocaudal distance between FLs (cm)	173	<0.001	120<100<80	<0.001	2<1	35.2 ± 1.3	33.9 ± 1.3	31.8 ± 1.3	67
Craniocaudal distance between HLs (cm)	173	<0.001	120<100<80	<0.001	2<1	13.5 ± 1.5	11.5 ± 1.4	7.3 ± 1.5	74
Craniocaudal distance between LeFL and TrHL (cm)	173	<0.001	120<100<80	<0.001	2<1	12.6 ± 1.3	11.1 ± 1.2	7.4 ± 1.2	59
Mediolateral distance between FLs (cm)	173	<0.001	80<120, 100<120	0.462		8.0 ± 0.7	8.4 ± 0.6	9.4 ± 0.7	73
Mediolateral distance between HLs (cm)	173	<0.001	80<120, 100<120	<0.001	1<2	12.7 ± 0.5	13.0 ± 0.5	14.2 ± 0.5	76
Craniocaudal distance between TrHL and trunk marker (cm)	173	<0.001	120<80, 120<100	<0.001	1<2	6.3 ± 0.6	5.9 ± 0.5	4.4 ± 0.5	57
Craniocaudal distance between LeHL and trunk marker (cm)	174	<0.001	120<80, 120<100	<0.001	1<2	5.9 ± 0.5	5.4 ± 0.5	4.1 ± 0.5	41
Limb angle									
TrFL at touch-down (˚)	170	<0.001	120<100<80	0.005	1<2	72.8 ± 0.9	71.3 ± 0.9	68.5 ± 0.9	67
TrFL at lift-off (˚)	173	<0.001	120<100<80	<0.001	2<1	131.0 ± 0.8	129.9 ± 0.8	128.0 ± 0.8	68
LeFL at touch-down (˚)	173	<0.001	120<100<80	<0.001	1<2	71.4 ± 0.6	69.9 ± 0.6	67.5 ± 0.6	42
LeFL at lift-off (˚)	174	<0.001	120<100<80	<0.001	2<1	118.6 ± 1.0	116.5 ± 1.0	112.5 ± 1.0	67
TrHL at touch-down (˚)	173	<0.001	120<80, 120<100	0.030	1<2	66.6 ± 0.6	65.7 ± 0.5	62.9 ± 0.6	41
TrHL at lift-off (˚)	175	<0.001	120<100<80	<0.001	2<1	127.3 ± 0.7	125.2 ± 0.7	121.8 ± 0.7	62
LeHL at touch-down (˚)	174	<0.001	120<80, 120<100	<0.001	1<2	65.6 ± 0.7	65.0 ± 0.7	63.3 ± 0.7	48
LeHL at lift-off (˚)	176	<0.001	120<100<80	0.018	2<1	123.9 ± 0.9	121.5 ± 0.9	119.1 ± 0.9	69

CI = confidence interval, ICC = intraclass correlation coefficient, TD = touch-down, TrFL = trailing forelimb, LeFL = leading forelimb, TrHL = trailing hindlimb, LeHL = leading hindlimb.

Main effects for bar height and stride number are presented as p-values along with estimated marginal means for all bar heights. Different shade of orange background indicates significant difference (p<0.05) between bar heights. Darker background denotes higher value. White background indicates no differences between bar heights. All p-values of pairwise comparison for bar height are presented in S3 Table. Estimated marginal means for stride numbers are presented in S4 Table.

[a] Lower values indicate greater synchronicity.

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Table 4. Linear mixed model results: Effect of bar height and approach stride number on sagittal joint kinematics at take-off to a jump in agility dogs.

Variable		Main effects				Estimated marginal mean ± SE			ICC
		Bar height		Stride number		Bar height:			
	N	p-value	Difference	p-value	Difference	80%	100%	120%	%
Trailing forelimb									
Shoulder peak flexion (˚)	167	0.23		<0.001	1<2	115.0 ± 1.5	114.6 ± 1.5	114.1 ± 1.5	82
Shoulder peak extension (˚)	167	<0.001	80<120, 100<120	<0.001	1<2	128.2 ± 2.1	129.2 ± 2.1	131.2 ± 2.1	88
Shoulder ROM (˚)	167	<0.001	80<120, 100<120	0.67		13.3 ± 1.4	14.7 ± 1.4	17.2 ± 1.4	68
Elbow peak flexion (˚)	168	<0.001	120<100<80	0.003	1<2	124.5 ± 2.0	122.7 ± 2.0	119.2 ± 2.0	78
Elbow peak extension (˚)	168	0.014	120<80	0.134		159.5 ± 1.2	158.4 ± 1.2	157.6 ± 1.2	66
Elbow ROM (˚)	168	<0.001	80<120, 100<120	0.058		34.8 ± 1.0	35.5 ± 1.0	38.1 ± 1.0	48
Carpus peak flexion (˚)	171	0.872		0.746		184.5 ± 2.3	184.2 ± 2.2	184.7 ± 2.2	77
Carpus peak extension (˚)	171	0.002	80<120, 100<120	0.213		234.7 ± 2.9	235.6 ± 2.9	238.1 ± 2.9	84
Carpus ROM (˚)	171	0.007	80<120, 100<120	0.148		50.4 ± 1.5	51.6 ± 1.5	53.7 ± 1.5	48
Leading forelimb									
Shoulder peak flexion (˚)	171	0.040	80<100	0.251		118.8 ± 2.0	120.1 ± 1.9	119.7 ± 1.9	89
Shoulder peak extension (˚)	171	0.355		0.183		140.6 ± 2.1	140.9 ± 2.1	141.5 ± 2.1	86
Shoulder ROM (˚)	171	0.151		<0.001	2<1	21.6 ± 0.9	20.7 ± 0.9	21.7 ± 0.9	57
Elbow peak flexion (˚)	171	0.180		0.002	1<2	124.6 ± 2.3	125.8 ± 2.3	124.3 ± 2.3	81
Elbow peak extension (˚)	171	0.343		0.557		162.5 ± 1.3	163.4 ± 1.2	162.9 ± 1.2	68
Elbow ROM (˚)	171	0.460		<0.001	2<1	37.7 ± 1.6	37.5 ± 1.5	38.4 ± 1.5	70
Carpus peak flexion (˚)	172	0.413		0.218		187.3 ± 1.9	187.6 ± 1.9	186.5 ± 1.9	74
Carpus peak extension (˚)	172	0.017	80<100, 80<120	<0.001	2<1	230.2 ± 3.1	233.0 ± 3.1	232.5 ± 3.1	84
Carpus ROM (˚)	172	0.018	80<100, 80<120	<0.001	2<1	43.1 ± 2.1	45.7 ± 2.1	46.3 ± 2.1	63
Trailing hindlimb									
Hip peak flexion (˚)	172	<0.001	120<80, 120<100	<0.001	2<1	129.8 ± 1.9	129.7 ± 1.9	127.4 ± 1.9	80
Hip peak extension (˚)	172	0.625		0.003	2<1	171.5 ± 1.5	171.9 ± 1.5	172.2 ± 1.5	71
Hip ROM (˚)	172	<0.001	80<120, 100<120	0.141		41.6 ± 1.1	42.1 ± 1.1	44.7 ± 1.1	63
Stifle peak flexion (˚)	172	0.647		0.722		130.4 ± 1.4	130.7 ± 1.4	129.8 ± 1.4	50
Stifle peak extension (˚)	172	<0.001	80<120, 100<120	0.949		155.9 ± 1.3	156.1 ± 1.3	157.6 ± 1.3	84
Stifle ROM (˚)	172	0.001	80<120, 100<120	0.107		25.3 ± 0.9	25.2 ± 0.8	26.7 ± 0.8	31
Tarsus peak flexion (˚)	172	<0.001	120<80, 120<100	<0.001	1<2	107.6 ± 1.8	106.0 ± 1.8	102.9 ± 1.8	65
Tarsus peak extension (˚)	172	0.945		0.595		174.6 ± 1.3	174.4 ± 1.3	174.4 ± 1.3	82
Tarsus ROM (˚)	172	<0.001	80<120, 100<120	<0.001	2<1	67.0 ± 1.2	68.4 ± 1.2	71.5 ± 1.2	47
Leading hindlimb									
Hip peak flexion (˚)	172	0.172		0.618		131.2 ± 2.4	132.2 ± 2.4	132.6 ± 2.4	85
Hip peak extension (˚)	172	0.022	80<120	0.054		168.2 ± 2.4	169.1 ± 2.4	170.4 ± 2.4	85
Hip ROM (˚)	172	0.534		0.010	1<2	37.1 ± 1.4	36.9 ± 1.4	37.7 ± 1.4	60
Stifle peak flexion (˚)	172	<0.001	120<80, 120<100	0.101		135.0 ± 1.4	135.8 ± 1.4	133.1 ± 1.4	67
Stifle peak extension (˚)	172	0.857		0.021	2<1	161.1 ± 1.3	160.9 ± 1.3	160.9 ± 1.3	84
Stifle ROM (˚)	172	<0.001	80<120, 100<120	0.801		26.0 ± 0.8	25.0 ± 0.8	27.8 ± 0.8	48
Tarsus peak flexion (˚)	172	<0.001	120<80, 120<100	0.437		107.7 ± 1.7	109.2 ± 1.7	105.3 ± 1.7	60
Tarsus peak extension (˚)	172	0.002	80<120, 100<120	0.350		175.2 ± 1.0	176.0 ± 1.0	176.9 ± 1.0	71
Tarsus ROM (˚)	172	<0.001	80<120, 100<120	0.178		67.4 ± 1.6	66.7 ± 1.6	71.5 ± 1.6	60

N = number of trials, CI = confidence interval, ICC = intraclass correlation coefficient, ROM = range of motion.

Main effects for bar height and stride number are presented as p-values along with estimated marginal means for all bar heights. Different shade of orange background indicates significant difference (p<0.05) between bar heights. Darker background denotes greater flexion, extension, or ROM. White background indicates no differences between bar heights. All p-values of pairwise comparisons for bar height are presented in S5 Table. Estimated marginal means for stride numbers are presented in S6 Table.

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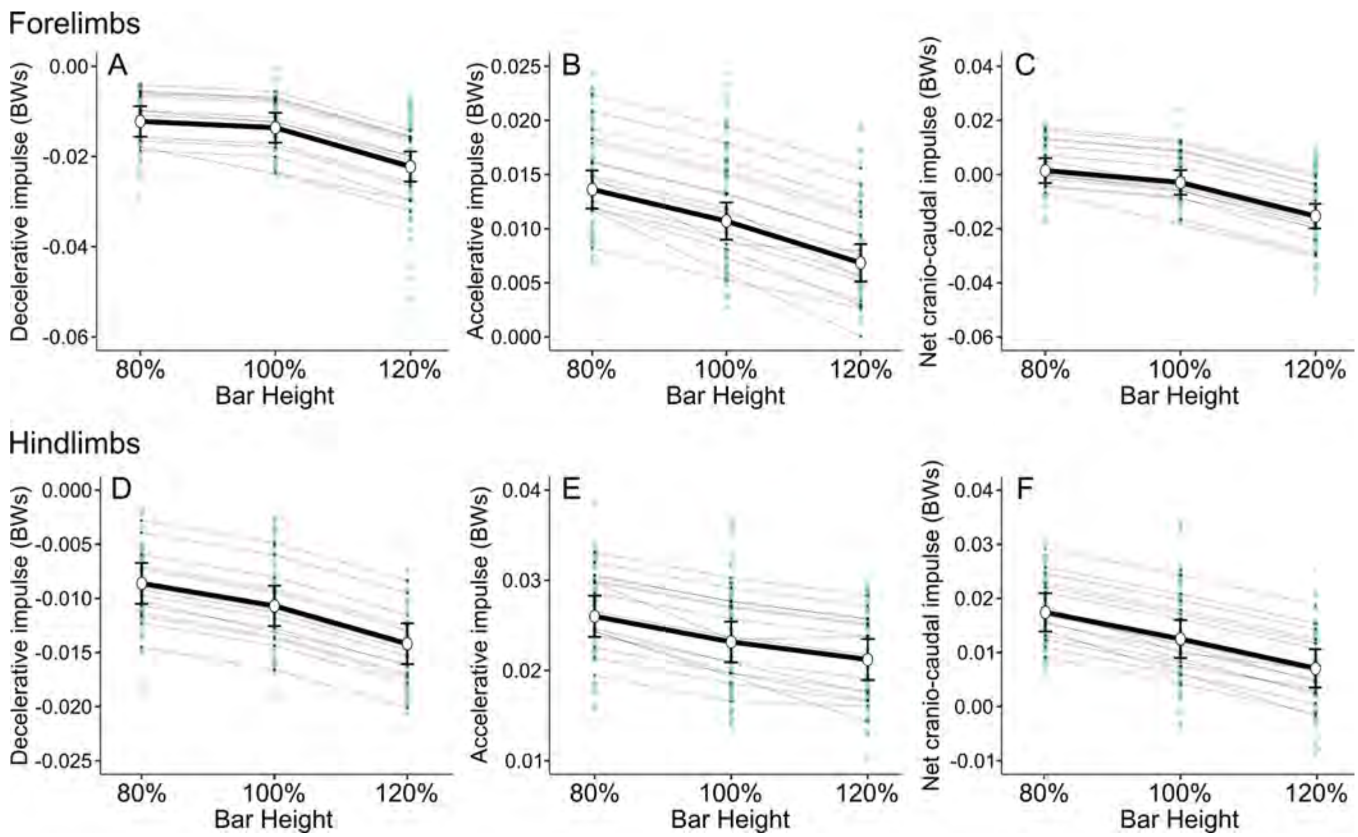

Fig 3. Craniocaudal impulses of fore- and hindlimbs at three bar heights during take-off. Estimated marginal means are presented as white dots along with 95% confidence interval lines. Light blue dots represent the observed values and light gray lines the random effects. A-C: Decelerative, accelerative, and net craniocaudal impulses produced by forelimbs. D-F: Decelerative, accelerative, and net craniocaudal impulses produced by hindlimbs. In both fore- and hindlimbs, all bar heights differed significantly from each other in all craniocaudal impulses ($p \leq 0.001$), except for decelerative impulse (A), which did not significantly differ between 80% and 100% bar heights in forelimbs.

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accelerative impulse between 80% and 120% heights was -0.007 BWs in forelimbs and -0.005 BWs in hindlimbs.

The net craniocaudal impulse of fore- and hindlimbs was affected by bar height ($p<0.001$), with post-hoc analyses showing differences between all bar heights ($p \leq 0.001$ for all pairwise comparisons) (Fig 3). The estimated difference between 80% and 120% heights was -0.017 BWs in forelimbs and -0.010 BWs in hindlimbs. The net craniocaudal impulse decreased from accelerative to decelerative in forelimbs and remained accelerative in hindlimbs at all bar heights.

There was a main effect of bar height on total vertical impulse produced during take-off by all four limbs ($p<0.001$). All bar heights differed from each other in post-hoc analyses ($p \leq 0.001$). The estimated difference between 80% and 120% heights was 0.052 BWs. The net craniocaudal impulse was affected by bar height ($p<0.001$), with all bar heights differing from each other ($p<0.001$). The estimated difference between 80% and 120% heights in net cranio-caudal impulse was -0.026 BWs, shifting the net impulse from accelerative to decelerative.

Effect of bar height on jump arch and velocity

Bar height affected the jump arch and velocity of the dog (Table 3). The height of the trunk at touch-down of trailing forelimb was affected by the bar height ($p<0.001$), with post-hoc analyses showing differences between all bar heights ($p<0.001$ for all pairwise comparisons). The estimated difference between 80% and 120% heights was -2.6% of wither height. There was a main effect of bar height for take-off distance ($p = 0.012$), with differences between 80% and 100% heights (β = -8 cm, $p = 0.010$) and 80% and 120% heights (β = -9 cm, $p = 0.009$).

There was a main effect of bar height on trunk height at the apex of jump ($p<0.001$), with all bar heights differing from each other ($p<0.001$). The estimated increase between 80% and 120% heights was 39.4% of wither height. However, there was also a main effect of bar height on bar clearance ($p<0.001$), with post-hoc analyses showing differences between 80% and 100% heights (β = -7.2%, $p<0.001$) and 100% and 120% heights (β = 6.6%, $p<0.001$). Thus, at 100% height the bar clearance was less than at other heights, with no difference between 80% and 120% heights.

Horizontal velocity at approach, just before touch-down of trailing forelimb, was affected by bar height ($p<0.001$) with differences between all bar heights ($p = 0.003$ for 80% vs. 100% comparison, $p<0.001$ for other comparisons). Additionally, there was a main effect of bar height on horizontal velocity after lift-off ($p<0.001$), with all three bar heights differing from other heights ($p<0.001$ for all pairwise comparisons). The estimated difference in horizontal velocity between 80% and 120% heights was -0.41 m/s at approach and -0.69 m/s after lift-off.

Effect of bar height on limb coordination

Positioning and timing of limbs were affected by bar height (Table 3). Stance times were longer in all limbs at 120% height. In trailing and leading forelimbs, bar height had an effect on stance time ($p<0.001$ for both forelimbs), with differences between 80% and 120% heights ($p<0.001$ for both forelimbs) and 100% and 120% heights ($p<0.001$ for TrFL, $p = 0.002$ for LeFL). The estimated increase in stance time between 80% and 120% heights was 9 ms in TrFL and 5 ms in LeFL. Similarly, in both hindlimbs, there was a main effect of bar height for stance time ($p<0.001$), with differences between 80% and 120% heights ($p<0.001$ for both TrHL and LeHL) and 100% and 120% heights ($p<0.001$ for both TrHL and LeHL). The estimated increase in stance time between 80% and 120% heights was 5 ms in TrHL and 6 ms in LeHL.

In fore- and hindlimbs, bar height affected limb synchronicity ($p<0.001$ for both limb pairs) (Fig 4), with differences between all bar heights (80% vs. 100%, $p = 0.048$ in FLs and $p = 0.006$ in HLs, $p<0.001$ for other pairwise comparisons). The estimated difference between 80% and 120% heights was -6.1% of TrFL stance time in forelimbs and -9.6% of TrHL stance time in hindlimbs, with lower values at 120% height indicating greater synchronicity.

The positioning of the paws relative to each other was affected by bar height. There was a main effect of bar height for craniocaudal distance between trailing and leading fore- and hindlimbs ($p<0.001$). Post-hoc analysis revealed differences between all bar heights (80% vs. 120%, $p<0.001$ in FLs and HLs, 80% vs. 100%, $p = 0.037$ in FLs and $p = 0.003$ in HLs, 100% vs. 120%, $p\leq0.001$ in FLs and HLs). The estimated difference in paw distance between 80% and 120% heights was -3.5 cm in forelimbs and -6.2 cm in hindlimbs. The craniocaudal distance between trailing forelimb and leading hindlimb was additionally affected by bar height ($p<0.001$), with differences emerging between all bar heights (80% vs. 100%, $p = 0.039$, $p<0.001$ for other pairwise comparisons). The estimated difference between 80% and 120% heights was -5.1 cm, indicating that fore- and hindlimbs were closer to each other at 120% height.

Mediolateral distance between trailing and leading limbs was affected by bar height in fore- and hindlimbs ($p<0.001$ for both limb pairs), with differences between 80% and 120% heights ($p<0.001$ for both limb pairs) and 100% and 120% heights ($p<0.001$ for both limb pairs). The estimated increase in mediolateral paw distance between 80% and 120% heights was 1.4 cm in forelimbs and 1.5 cm in hindlimbs.

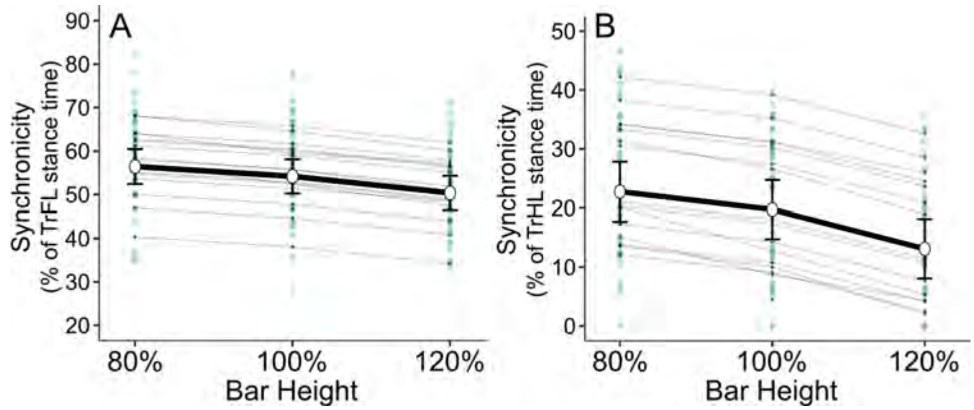

Fig 4. Synchronicity in touch-down timings of trailing and leading forelimbs (A) and hindlimbs (B). Estimated marginal mean is presented as a white dot along with the 95% confidence interval line. Light blue dots represent the observed values and light gray lines the random effects. Synchronicity is presented as the percentage of trailing limb stance time at which leading limb touch-down occurs. Lower value indicates more synchronous touch-down of trailing and leading limbs. In both fore- and hindlimbs, values differed significantly between all bar heights (80% vs. 100%, $p = 0.048$ in forelimbs and $p = 0.006$ in hindlimbs, $p<0.001$ for other pairwise comparisons). TrFL = trailing forelimb, TrHL = trailing hindlimb.

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Effect of bar height on limb angle

In all four limbs, the limb angle was always below 90˚ (vertical) at touch-down and above 90˚ at lift-off. In all limbs, the limb angle decreased at both touch-down and lift-off as bar height increased (Table 3). The limb angle of the trailing forelimb was affected by the bar height both at touch-down and at lift-off ($p<0.001$), with all three heights differing from each other ($p = 0.002$ at TD and $p = 0.003$ at LO 80% vs. 100%, $p<0.001$ for other pairwise comparisons at TD and LO). The estimated difference between 80% and 120% heights was -4.3˚ at touch-down and -3.1˚ at lift-off. Similarly, there was a main effect of bar height on limb angle of leading forelimb at touch-down ($p<0.001$) and lift-off ($p<0.001$), with differences between all bar heights ($p\leq0.001$ at both TD and LO). The estimated difference between 80% and 120% heights was -3.9˚ at touch-down and -6.2˚ at lift-off.

In the trailing hindlimb, the bar height affected limb angle at touch-down ($p<0.001$) and lift-off ($p<0.001$). At touch-down, post-hoc analyses revealed differences between 80% and 120% heights ($\beta = -3.6$˚, $p<0.001$) and 100% and 120% heights ($\beta = -2.8$˚, $p<0.001$). At lift-off, all three bar heights differed from each other ($p<0.001$), with the estimated difference between 80% and 120% heights being -5.5˚. Additionally, the bar height affected limb angle of leading hindlimb at touch-down ($p<0.001$) and lift-off ($p<0.001$). At touch-down, differences were observed between 80% and 120% heights ($\beta = -2.3$˚, $p<0.001$) and 100% and 120% heights ($\beta = -1.7$, $p = 0.001$). At lift-off, all three bar heights differed from each other ($p<0.001$), with an estimated difference between 80% and 120% heights of -4.9˚.

Effect of bar height on sagittal joint kinematics in forelimbs

The sagittal joint angles of shoulder, elbow, and carpal joints during stance phase at take-off are presented in Figs 5 and S2. Bar height had a significant main effect on peak extension, peak flexion, or ROM of multiple forelimb joints, especially in the trailing forelimb. Full results are presented in Table 4. Most differences were observed between 120% and lower heights, with no significant difference between 80% and 100% heights.

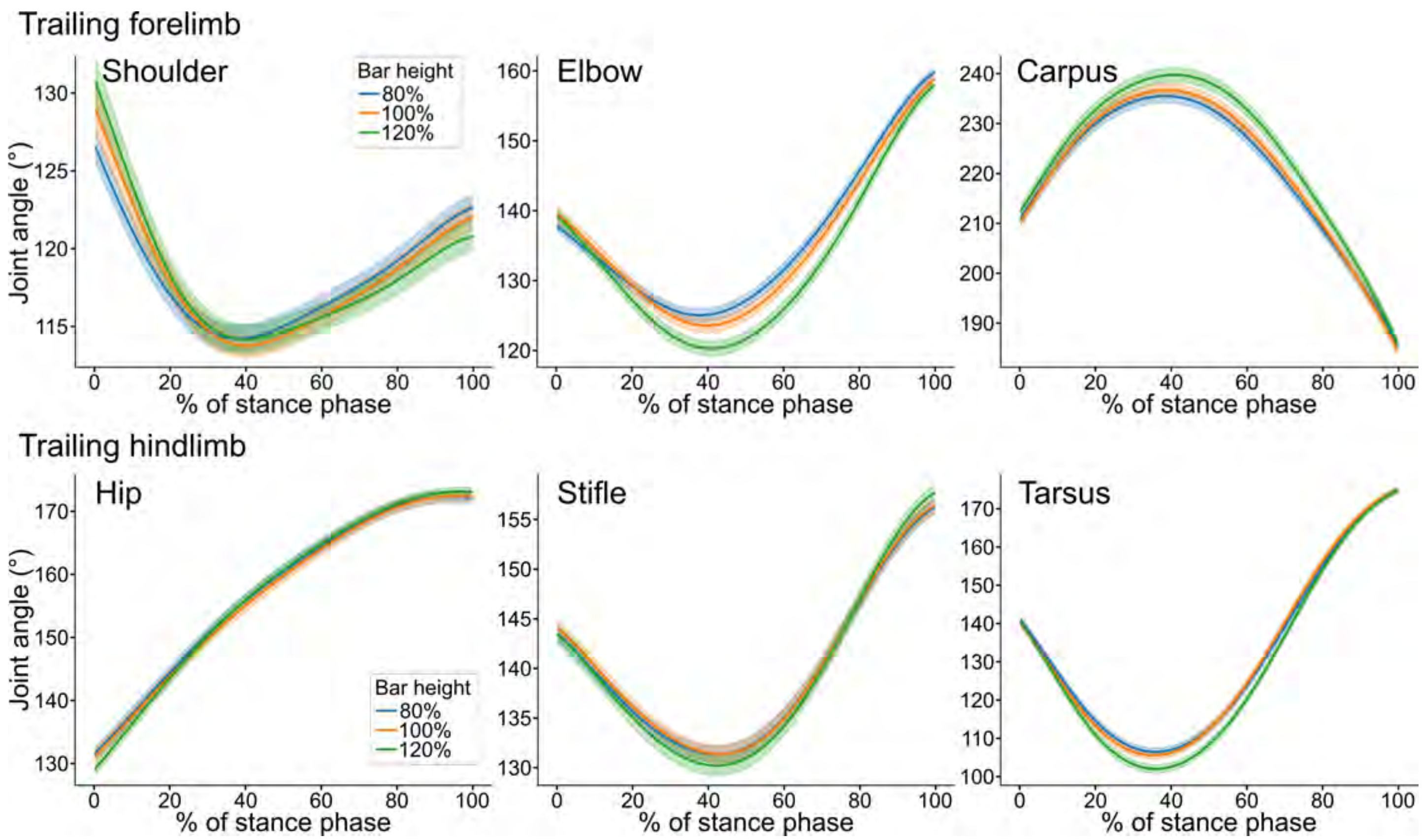

Fig 5. Sagittal joint angles during stance phase at take-off to a jump. Joint angles of trailing forelimb shoulder, elbow, and carpus and trailing hindlimb hip, stifle, and tarsus are presented. Mean curves ± standard error of mean from all trials at three bar heights are shown: 80% (blue), 100% (orange), and 120% (green) of wither height. Figures for leading fore- and hindlimb joints are presented in S2 Fig. Please note that the effect of stride number is not controlled in this figure, and the number of trials per dog per bar height varied from 0 to 7.

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In the trailing forelimb shoulder, there was a main effect of bar height on peak extension and ROM ($p<0.001$), with post-hoc analyses showing differences between 80% and 120% heights (peak extension $\beta = 3.0^\circ$, $p<0.001$; ROM $\beta = 3.8^\circ$, $p<0.001$) and 100% and 120% heights (peak extension $\beta = 2.0^\circ$, $p = 0.001$; ROM $\beta = 2.5^\circ$, $p<0.001$). In the trailing forelimb elbow, the peak flexion was affected by bar height ($p<0.001$), with all bar heights differing from each other ($p = 0.034$ for 80% vs. 100%, $p<0.001$ for other pairwise comparisons). The estimated difference between 80% and 120% heights was -5.3˚.

Additionally, bar height had an effect on peak extension of the trailing forelimb elbow ($p = 0.014$), but post-hoc analyses showed a difference only between 80% and 120% heights ($\beta = -1.9^\circ$, $p = 0.004$). Trailing forelimb elbow ROM was affected by bar height ($p<0.001$), with differences between 80% and 120% heights ($\beta = 3.4$, $p<0.001$) and 100% and 120% heights ($\beta = 2.7$, $p<0.001$).

In the carpal joint of the trailing forelimb, bar height had a main effect on peak extension ($p = 0.002$) and ROM ($p = 0.007$). Post-hoc analyses revealed differences between 80% and 120% heights (peak extension $\beta = 3.4^\circ$, $p<0.001$; ROM $\beta = 3.3^\circ$, $p = 0.002$) and 100% and 120% heights (peak extension $\beta = 2.5^\circ$, $p = 0.008$; ROM $\beta = 2.1^\circ$, $p = 0.039$).

In the leading forelimb, peak extension and carpal joint ROM were affected by bar height ($p = 0.017$ and $p = 0.018$, respectively), with differences between 80% and 100% heights (peak extension β = 2.8˚, p = 0.007; ROM β = 2.6˚, p = 0.025) and 80% and 120% heights (peak extension β = 2.3˚, p = 0.027; ROM β = 3.1˚, p = 0.008).

Effect of bar height on sagittal joint kinematics in hindlimbs

Sagittal joint angles of hip, stifle, and tarsal joints during stance phase at take-off are presented in Figs 5 and S2. There was an effect of bar height on peak extension, peak flexion, and ROM of multiple joints in both hindlimbs. The full results are presented in Table 4. In both hindlimbs, joint kinematics differed at the 120% height compared with the lower heights, whereas no differences were observed between 80% and 100% heights.

In the trailing hindlimb, peak flexion and ROM of hip joint were affected by bar height ($p<0.001$), with differences between 80% and 120% heights (peak flexion β = -2.4˚, $p<0.001$; ROM β = 3.2˚, $p<0.001$) and 100% and 120% heights (peak flexion β = -2.3˚, p = 0.001; ROM β = 2.6˚, $p<0.001$).

There was main effect of bar height on peak extension and ROM of the trailing hindlimb stifle ($p<0.001$). Post-hoc comparisons revealed significant differences between 80% and 120% heights (peak extension β = 1.7˚, $p<0.001$; ROM β = 2.4˚, p = 0.002) and 100% and 120% heights (peak extension β = 1.6˚, $p<0.001$; ROM β = 2.4˚, p = 0.001).

In the tarsus of the trailing hindlimb, bar height had an effect on peak flexion ($p<0.001$) and ROM ($p<0.001$), with post-hoc analyses showing differences between 80% and 120% heights (peak flexion β = -4.6˚, $p<0.001$; ROM β = 4.5˚, $p<0.001$) and 100% and 120% heights (peak flexion β = -3.1˚, p = 0.001; ROM β = 3.1˚, $p<0.001$).

In the hip joint of leading hindlimb, the bar height had an effect on peak extension (p = 0.022), with the only difference being between 80% and 120% heights (β = 2.2˚, p = 0.006). Stifle peak flexion and ROM were also affected by bar height ($p<0.001$), with differences between 80% and 120% heights (peak flexion β = -2.0˚, p = 0.009; ROM β = 1.8˚, p = 0.002) and 100% and 120% heights (peak flexion β = -2.8˚, $p<0.001$; ROM β = 2.8˚, $p<0.001$).

In the tarsal joint of the leading hindlimb, there was a main effect of bar height on peak flexion, peak extension, and ROM ($p\leq0.002$). For all variables, the pairwise differences were observed between 80% and 120% heights (peak flexion β = -2.4˚, p = 0.016; peak extension β = 1.7˚, $p<0.001$; ROM β = 4.1˚, $p<0.001$) and 100% and 120% heights (peak flexion β = -3.9˚, $p<0.001$; peak extension β = 0.9˚, p = 0.045; ROM β = 4.8˚, $p<0.001$).

Effect of approach stride number

In 118 in 176 trials (67%), dogs took one stride between obstacles 1 and 2 (one-stride approach), with the remaining trials utilizing a two-stride approach. No association between 'Bar height' and 'Stride number' (p = 0.74) was observed. There was individual variability in striding: 9 of the 17 dogs always used a one-stride approach, three dogs always a two-stride approach, and the remaining five dogs varied their striding.

When using a one-stride approach, dogs lowered the trunk before take-off (β = -1.5% of wither height, p = 0.017) and took off further away from the obstacle (β = 74 cm, $p<0.001$) with greater bar clearance (β = 17.3% of wither height, $p<0.001$) compared to a two-stride approach. Horizontal velocity after lift-off was greater with one-stride approach (β = 0.36 m/s, $p<0.001$). Fore- and hindlimbs were less synchronous (FLs: β = 4.7% of TrFL stance time, p = 0.010; HLs: β = 6.9% of TrHL stance time, $p<0.001$) when using a one-stride approach.

When using a one-stride approach, vertical impulses were greater in forelimbs (β = 0.044 BWs, $p<0.001$) and hindlimbs (β = 0.027 BWs, $p<0.001$) than with the two-stride approach. The weight was shifted more towards forelimbs with a one-stride approach (β = 1.4%, p = 0.011). The net craniocaudal impulse of all four limbs was greater with a one-stride approach (β = 0.016 BWs, $p<0.001$), indicating greater horizontal acceleration. Full results regarding the effect of approach stride number on the biomechanics at take-off are presented in Tables 3, 4, S2, S4 and S6.

Discussion

Increasing bar height resulted in multiple biomechanical adaptations at take-off to jump in agility dogs. The vertical and decelerative impulses produced by fore- and hindlimb pairs increased and accelerative impulses decreased with higher bar height. Bar height did not affect weight distribution between fore- and hindlimbs. The horizontal velocity of the dog decreased and take-off angle became steeper with increasing bar height, as hypothesized. As bar height increased, the temporal synchronicity increased in fore- and hindlimbs with decreased cranio-caudal distances between the paws. In most measured limb joints, the ROM was greater at 120% than at lower bar heights through greater peak flexion, peak extension, or both. The expected increase in hip peak flexion during take-off was observed only in trailing hindlimbs, and the expected increase in stifle peak flexion appeared only in the leading hindlimb. However, peak flexion increased in both tarsal joints at 120% bar height.

Kinetics

The effect of bar height on kinetics at take-off in agility dogs has not, to our knowledge, been reported previously. Increased total vertical impulse was required to jump over higher bars. Longer stance phases in all limbs allowed vertical forces to be produced over prolonged duration of time as bar height increased. The dogs in this study may have used this strategy to limit increase in peak vertical forces. Whether peak vertical forces of individual limbs were increased, could not be evaluated in this study.

Fore- and hindlimbs contributed equally to the increase in total vertical impulse produced during take-off with no change in weight distribution between fore- and hindlimbs. Around 53% of the total vertical impulse was produced by forelimbs at all bar heights, which is similar to previous reports of 55–56% in take-off to agility jump (bar height 90% of wither height) and 56–58% in galloping dogs [16,19–21].

The net craniocaudal impulse produced during take-off shifted from accelerative to decelerative through increased decelerative and decreased accelerative impulses from fore- and hindlimbs. Similar results have been reported in hindlimbs of horses at take-off [22]. This tactic may be used to redirect the mainly horizontal movement at approach into an increasingly vertical direction as bar height increases. In our study, the net craniocaudal impulse produced by hindlimbs remained accelerative at all heights, highlighting the role of hindlimbs in production of accelerative forces, as reported in galloping dogs [21].

The increased vertical and decelerative impulses associated with higher bar heights could increase the load on dogs' musculoskeletal tissues, predisposing to injuries—although this data does not allow to evaluate how these were altered in individual limbs. Repeated production of greater impulses during agility course and training sessions may lead more rapidly to fatigue when using high bar heights. In humans, acute fatigue reduces postural control and muscle strength, which in turn can increase injury risk [23]. In agility dogs, injuries occur more often towards the end of the training session or competition day, suggesting that fatigue may also contribute to injuries in agility dogs [2].

In humans, decelerations are associated with predominantly eccentric muscles actions [24]. In agility dogs, *musculus biceps brachii* and *musculus supraspinatus* show peak activations at the beginning of stance phase at take-off [25], when decelerative forces are produced and when shoulder joint is, according to our data, flexing. Eccentric muscle actions are associated with high muscle forces, which are transferred to the skeleton via tendons. This repetitive tensile loading may contribute to biceps and supraspinatus tendinopathies, which are among the most common injuries in agility dogs [26] and thought to result from overuse [27]. Higher bar heights may increase these loads through greater decelerative and vertical forces. However, the decelerative forces appear to be higher at take-off to a turning jump than in jumping in a straight line [16,28]. Whether decelerative forces of turning jumps are also associated with bar height and determination of the magnitudes of deceleration during other tasks on the agility course require further research.

Horizontal velocity and movement of the trunk

Bar height has been reported to reduce horizontal velocity over the bar jump [14]. Here, we showed that the horizontal velocity was decreased already when approaching the take-off as well as when lifting off into the jump's aerial phase. The higher the bar, the more kinetic energy has to be transferred into potential energy at take-off. Dogs' ability to perform this transfer of energy may be reduced at higher approach speeds, and thus, dogs slow down before take-off to a higher jump.

On the other hand, greater speed at lower bar heights, and therefore, greater kinetic energy, may increase the risk of injury in case of accidents, such as collisions or slips, which have been reported to cause injuries in agility [1,2]. Dog speed over faultless agility runs has, however, not been shown to be associated with risk for agility-related injuries [2], whereas in another dog sport, flyball, faster dogs do have higher risk for injuries [29,30]. However, in agility, bar height is probably not the only factor affecting speed over an agility course; for example, course design (number of turns, length of straight lines), surface or handler position may impact speed as well. Future studies should continue to investigate the effect of speed on injury risk in agility dogs.

Movement and position of the trunk were affected by bar height. When bar height increased, dogs lowered slightly their trunk when coming into take-off and after lift-off continued at a steeper angle. As expected, the calculated trunk height at the apex of the jump increased with bar height. However, the clearance between the trunk and bar was the least at 100% and greater at 80% and 120%. Thus, the height of the actual jump at 80% and 100% heights were quite close to each other, whereas the dogs jumped markedly higher at 120% bar height. This may explain why the two lower heights were often biomechanically less different to each other, and the highest height required the greatest biomechanical adjustments in the jump performance of the dog. As higher jump requires greater vertical force production at take-off to achieve higher vertical velocity and, therefore, requires more energy, the unnecessarily high bar clearance at 120% was not optimal strategy and increased the demands at this bar height even further. Additionally, knocking off a bar was observed almost exclusively at the highest bar height, suggesting that dogs may have struggled to perform at that height.

Limb coordination

In our study, the dogs changed their limb positions relative to the obstacle and to each other as bar height changed, whereas in ridden horses limb positions at take-off have been reported to remain relatively constant across difference obstacle heights [31]. In our sample, the take-off point was closer to the obstacle when bar height was at or above 100% of wither height. Dogs are known to adjust jump trajectory to minimize mechanical work [32]. Thus, the reduced take-off distance to higher bar height might be more efficient. Whether the length of the jump trajectory was altered, could not be evaluated in our study, but length of the jump trajectory has been reported to increase up to bar heights 100–125% of wither height with decrease in length when bar height is above 125% of wither height [14]. Additionally, landing distance from the first jump in the sequence, if altered by bar height, could have affected the take-off distance to the second jump, which was analyzed in our study.

Craniocaudal distances between all limbs decreased along with greater synchronicity in fore- and hindlimbs. This positioning of the limbs aids in rotating the trunk into more vertical position and in dividing vertical forces more equally between trailing and leading hindlimbs. At all bar heights, temporal synchronicity appeared to be greater than in high-speed rotary gallop on flat [19] with even more pronounced difference to gallop as bar height increased.

The limb angles at touch-down and lift-off were affected by bar height in our sample. As height increased, forelimbs contacted the ground with a greater protraction angle, thus, further in front of the center of gravity. This positioning is likely to have led to the increased deceleration during stance phases in forelimbs. At lift-off, all limbs were at a more vertical limb position (less retraction) when bar height increased, probably to produce a steeper take-off angle. This is likely to have resulted in shorter duration of the accelerative phase and decreased accelerative impulses.

Forelimb joint kinematics

Sagittal joint kinematics were altered by bar height in the trailing forelimb shoulder, elbow, and carpus as well as in the carpus of the leading forelimb. In an earlier study, no effect of bar height was observed when forelimb joint angles were measured from a single still frame towards the end of the stance phase [13]. Recording sagittal joint kinematics throughout the stance phase allowed us to observe effects that had not been reported previously. Greater adjustments in joint kinematics were observed in the trailing forelimb as bar height increased. The trailing forelimb has been reported to produce approximately 30% of the total vertical impulse at take-off to a jump, which is a higher percentage than for other limbs [16]. We were not able to record forces for individual limbs, but the trailing forelimb might have had a greater role in producing vertical force than the leading forelimb. It could explain why alterations in joint kinematics were observed mainly in the trailing forelimb. [16] In both forelimbs, the carpal joint showed greater peak extension, which occurred shortly before the midstance of take-off. The peak carpal extension was less than that reported in dogs entering A-frame [33] but similar to that of dogs landing from a jump or A-frame [34]. During all of these agility activities, the peak carpal extension is greater than in healthy dogs in trot [35–37]. Carpal joint injuries, such as sprains and hyperextension injuries, have been reported in agility dogs [2,4,26]. Further studies are needed to clarify, whether the estimated two-to-three-degree reduction in carpal extension at low bar heights, occurring at the end of joint's ROM, results in clinically relevant decrease in load on the carpal joint over repetitions.

Hindlimb joint kinematics

In both hindlimbs, we observed an effect of bar height on joint kinematics, with greatest ROM in almost all measured hindlimb joints at the 120% bar height. Thus, dogs are required to produce force over a greater ROM and at more extreme joint angles as bar height increases.

At 120% bar height, the trailing hindlimb had greater peak hip flexion by two degrees mean difference, occurring at the beginning of the stance. Hip flexion may have been used to produce the greater protraction of trailing hindlimb at limb touch-down when jumping higher bar heights. The hypothesized greater hip flexion was, however, not observed in the leading hindlimb. The leading hindlimb had greater peak hip extension, although only by 2.2 degrees, at the highest height, which occurred towards the end of the stance. The greater hip extension probably allowed the trunk of the dog to take a more vertical position during lift-off. However, the peak extension values of the hip joint appear to be slightly greater in the trailing hindlimb than in the leading hindlimb. In both hindlimbs, the extension angles were greater than those reported for most breeds in low-speed gallop or in passive ROM measurements [38,39].

When the hip is extended, the *musculus iliopsoas*, one of the most injured muscles in agility dogs [3,4,40], is stretched. When the dog performs a vertical jump from stand position, in which the hindlimb action resembles that of jumping over an obstacle, *m. iliopsoas* is activated from beginning to end of the stance phase [41]. As previously described, eccentric muscle actions can cause muscle damage, which increases with greater stretch of the muscle [42]. Extension of the hip, with concurrent stretch and possibly activation of *m. iliopsoas*, during the jump take-off may contribute to the chronic injuries of *m. iliopsoas*, which are thought to result from repetitive microtrauma [43]. However, bar height only affected extension in the hip joint of the leading hindlimb, whereas the more marked extension of the trailing hindlimb hip joint was unaltered by bar height. Thus, reduction of bar height, at least in the ranges evaluated by this study, might not mitigate the risk for iliopsoas injuries in agility dogs.

In the leading hindlimb, there was greater peak extension of the tarsal joint (end of stance) at the highest height, which has been previously reported when comparing take-off at two bar heights (93% and 151%) [13]. As the tarsal peak extension values in our study were beyond those reported for passive extension and extension during gallop [37,38], even the estimated 1.7-degree difference could be clinically relevant considering the repeated nature of jumping in agility. In our study, at 120% height, both tarsal joints had additionally greater peak flexion, which occurred around the first third of the stance. Similarly, increased peak flexion and ROM of both tarsal joints have been observed with increasing horizontal acceleration in greyhounds on flat ground [44]. As higher jump requires greater vertical velocity at lift-off and, therefore, greater vertical acceleration during take-off, agility dogs may utilize similar strategies to increase vertical acceleration during jumping as greyhounds use on flat to increase horizontal acceleration.

Other factors affecting jumping biomechanics

Previous studies on jump biomechanics in agility dogs have not reported the number of strides between jumps even when multi-obstacle sequences have been used [14,16,45,46]. The multi-obstacle sequences enable course-like speed and performance, thus allowing evaluation of truly sport-specific movement. For these reasons, we used a sequence of three jumps in our set-up. The number of strides between two jump obstacles varied individually across dogs as well as within dogs in a consistent sequence even for the same bar height. However, no association between the number of strides and bar height was observed. Our study showed that stride number was associated with multiple biomechanical differences in kinetics and kinematics. Thus, it was important to control for the effect of stride number in the statistical model to evaluate the effects of bar height more accurately. Additionally, these results highlight the complexity of the sport; i.e. multiple factors affect the loads put on these dogs even in a simple sequence as in straight-line jumps, with the bar height being just one factor. Future biomechanical studies on agility dogs should report and, if needed, control for striding within the obstacle sequence.

Additionally, the high intraclass correlation coefficients indicate a marked individual variation in the biomechanics of jumping; the random factor accounting for the variability among dogs explained a higher proportion of the variation than stride number or bar height. The highest individual variation was observed in joint peak flexion and peak extension angles, which may be affected by conformation of the dog. Horizontal velocity and take-off distance also varied markedly between individuals.

Limitations

The sample size calculated through power analyses was not achieved, which may result in type 2 errors (false negatives). Yet almost all hypothesized effects of bar height were confirmed. Additionally, the power calculations were a rough estimate, as methods, evaluated joint angles, and sample of dog breeds differed markedly.

Due to the size and orientation of the force plates, forces from individual limbs could not be measured. Therefore, for example, peak forces could not be calculated for each limb individually. Forces are not distributed evenly to trailing and leading limbs [16] and the combined forces do not provide full information of the loads on individual limbs. The greater temporal synchronicity at higher bar heights has probably contributed to the greater vertical peak forces measured from limb pairs in this study. Additionally, decelerative and accelerative impulses were calculated as a sum of trailing and leading limb forces. Therefore, there were time points where accelerative forces produced by one of the limbs may have been cancelled the decelerative forces produced by another limb. Thus, the values of decelerative and accelerative impulses do not depict the total decelerative or total accelerative forces produced by two limbs. However, the net craniocaudal impulse values are not affected. Future studies should evaluate the forces from individual limbs at take-off to jump obstacles of varying height and possibly investigate net joint moments and limb stiffness as well.

Measured ground reaction forces were associated with other measured variables such as velocity, take-off angle and limb synchronicity, which were not included as covariates in the final statistical model because they were associated with bar height. In this study, we did not aim to fit models that best predicted each dependent variable. Rather, we chose to keep the model simple and easy to interpret and discuss, considering the numerous dependent variables in this study and limited sample size. Our focus was on how alteration of bar height, choice made by humans, affects the dog in a sport-specific environment where the dog can choose to make multiple alterations to its performance in response to the altered bar height.

The highest bar height in our study was probably above the bar height that some of the participating dogs were used to jumping. This was likely especially in dogs whose wither height was at the higher end of their height category (jumping usually lower proportional bar heights) and in younger dogs who had not competed before the regulation changes where jump heights were reduced. Although handlers were informed about their dogs' individual bar heights beforehand and encouraged to familiarize their dog with the bar heights if needed, it is possible that inexperience in jumping at 120% bar height may have influenced the results.

The sequence of jumps allowed for evaluation of bar height effects in sport-specific setting, but as a result, the observed bar height effects might, to certain degree, be specific to this sequence. Each sequence, or even placement of start line, restricts the choices for the dog: for example, in our setup the dogs were forced to take either one or two strides between two obstacles. Restriction of take-off point has been shown to affect the jump trajectory as dogs aim to minimize the mechanical energy cost [32]. Evaluation of bar height effects in other sequence (e.g. different spacing or approach from tunnel) is recommended for future research.

Skin displacement is known to produce error in marker-based kinematic data in dogs, especially in the proximal joints [47–49]. Unfortunately, there is currently no means to account for this error in jumping dogs. Therefore, the reported absolute joint angle values should be interpreted with caution, especially regarding shoulder and hip joint values. While the same measurement system was used at all bar heights, differences in performance, such as change in velocity, may have affected the degree of skin displacement error at different bar heights.

Conclusion

The increase in bar height resulted in multiple biomechanical adaptations in jumping performance of agility dogs. Dogs decelerated more, accelerated less, and produced greater vertical impulse during take-off with fore- and hindlimbs when bar height increased. With increasing bar height, limbs were positioned closer to each other in craniocaudal direction with greater temporal synchronicity. Additionally, sagittal ROM of most limb joints was greater at 120% than at lower heights. Increased vertical and decelerative impulses as well as greater peak flexion or extension angles of joints may indicate greater load on tissues at higher bar heights in a straight-line jump sequence, which may contribute to sport-related injuries in agility dogs.

Supporting information

S1 Fig. Calculation of peak force and impulse values from trial with overlap. This figure shows an individual trial at 100% bar height. In some trials leading forelimb and trailing hindlimb contacted same force plate simultaneously, leading to their force curves overlapping with each other. To estimate fore- and hindlimb impulses from these trials, the lowest vertical force value was used as cut-off: Force values before the cut-off timing were used to calculate forelimb impulses and values after it for hindlimb impulses. The magnitude of overlap was assessed by the value of vertical force at the cut-off point. This approach was used only for trials where the magnitude of overlap was below 0.4 BW. In the depicted trial, magnitude of overlap was 0.36 BW.
(TIF)

S2 Fig. Sagittal joint angles of during stance phase at take-off to a jump. Joint angles of leading forelimb shoulder, elbow and carpus, and leading hindlimb hip, stifle and tarsus. Mean curves ± standard error of mean from all trials at three bar heights are shown: 80% (blue), 100% (orange) and 120% (green) of wither height.
(TIF)

S1 Table. Linear mixed model results: Main effect of bar height and pairwise differences in kinetics at take-off to a jump in agility dogs.
(DOCX)

S2 Table. Linear mixed model results: Main effect of approach stride number on kinetics at take-off to a jump in agility dogs.
(DOCX)

S3 Table. Linear mixed model results: Main effect of bar height and pairwise differences on jump arch and limb coordination at take-off to a jump in agility dogs.
(DOCX)

S4 Table. Linear mixed model results: Main effect of approach stride number on jump arch and limb coordination at take-off to a jump in agility dogs.
(DOCX)

S5 Table. Linear mixed model results: Main effect of bar height and pairwise differences in sagittal joint kinematics at take-off to a jump in agility dogs.
(DOCX)

S6 Table. Linear mixed model results: Main effect of approach stride number on sagittal joint kinematics at take-off to a jump in agility dogs.
(DOCX)

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Author Contributions

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Part II of Finnish Agility Dog Survey: Agility-Related Injuries and Risk Factors for Injury in Competition-Level Agility Dogs

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Simple Summary: Agility dogs can get injured during sports performance. Only a few factors have been linked to risk for injury. Through an online questionnaire, information was collected of more than 860 Finnish competition-level agility dogs. Of these dogs, 119 (14%) had suffered an injury in agility during calendar year 2019. Front limbs were most commonly injured. Typically, the injury presented as lameness. In general, dogs regained their performance level in four weeks, but 10% of injured dogs retired from the sport due to the injury. Dogs with multiple previous agility-related injuries or a diagnosis of lumbosacral transitional vertebra had higher odds of getting injured. Other common factors among the injured dogs included older age when starting course-like training and more than two agility-training sessions a week. A moderate number of monthly competition runs and an A-frame performance technique had lower odds of injury. This study identified new risk factors for injury in agility. This information can be used to improve the welfare of agility dogs.

Abstract: Dog agility is associated with a risk for sport-related injuries, but few risk factors for injury are known. A retrospective online questionnaire was used to collect data on 864 Finnish competition-level agility dogs—including 119 dogs (14%) with agility-related injury during 2019. Data included injury details, health background, experience in agility, and sport and management routines prior to the injury. Risk factors for injury were evaluated with multivariate logistic regression. The rate of competition-related injuries was 1.44 injuries/1000 competition runs. The front limb was injured in 61% of dogs. In 65% of dogs, the injury presented as lameness. The main risk factors for agility-related injury during 2019 were multiple previous agility-related injuries (OR 11.36; 95% CI 6.10–21.13), older age when starting course-like training (OR 2.04 per one year increase; 95% CI 1.36–3.05), high training frequency, diagnosis of lumbosacral transitional vertebra, and physiotherapy every two to three months compared with never. The most important protective factors were moderate competition frequency and A-frame performance technique. These associations do not confirm causality. We identified new risk factors for injury in agility. This information can be used to improve the welfare of agility dogs.

Keywords: dog agility; canine sports medicine; agility-related injury; sport-related injury; injury risk; agility training; risk factor; lumbosacral transitional vertebrae

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1. Introduction

Agility is a growing dog sport with over 100,000 yearly competition runs in Finland alone [1]. Based on the four survey studies known to us, 8–33% of agility dogs suffer agility-related injury [2–5]. However, the evaluation periods of the four studies varied markedly, ranging from three months to potentially the whole sporting career of the dog [2–5]. The rate of agility-related injuries in competitions has been reported to be 2.12 per 1000 runs [3]. Almost half of the injuries in agility dogs require at least six to eight weeks for recovery, and 12% of injured dogs retire from agility due to the sport-related injury [2,4]. Most previous studies have been done almost exclusively in North American agility dogs [2–5]. However, regional differences occur in training and management routines [6,7], possibly affecting the risk of injury. Additionally, frequency of orthopedic conditions and injuries in agility dogs, including injuries not necessarily related to agility, also varies by geographic region [8]. Thus, occurrence of agility-related injuries and risk factor for injuries should be evaluated in different populations.

Some risk factors for agility-related injuries have been reported. Previous agility-related injury significantly increases the odds of additional injuries [7]. However, whether other musculoskeletal injuries and orthopedic conditions are associated with risk for agility-related injuries has, to our knowledge, not been evaluated yet. Chronic conditions could be provoked by agility or affect dogs' ability to safely perform in the sport, predisposing to accidents.

Border Collie breed, the most common breed in agility, is consistently reported to be at increased risk of agility-related injuries [3–5,7,9], possibly due to their higher speed over obstacle sequences [10]. Speed of the dog may, however, be a risk factor independent of breed, but it has not been evaluated in earlier studies. In flyball, for instance, fast dogs were at increased risk of injuries [11]. Anecdotally, agility dogs perform at their full speed, and high velocities lead to increased kinetic energy. This may result in injury, for instance, in the case of collision with an obstacle, which is a common cause of agility-related injury [2].

In previous survey studies evaluating risk factors for injuries in agility, the competition, training, and management routines at the time of or prior to participation have been asked, without temporal association with injury [5,7]. However, these routines are not necessarily related to routines prior to the injury. This may be the reason why no relationship has been found between training or competition frequency and injuries [3,5,7]. Reverse causality may have caused musculoskeletal care, such as chiropractic care and massage, to be associated with agility-related injuries in previous studies, as these have been probably used for treatment of the injury [3,7].

Multiple other factors, such as field surface, fence height in relation to a dog's height, and amount of daily exercise, have not yet been evaluated as risk factors for injury. The Finnish Agility Association acknowledged the lack of scientific knowledge regarding safety in agility and highlighted the need for research on this topic. Further information on obstacles, surfaces, or training routines associated with injuries could affect practices or regulations aiming to reduce injuries. More detailed knowledge on the dog-related factors associated with injury, such as size or history of musculoskeletal diseases or injuries, could improve identification of dogs at greater risk of injury.

The overall aim of this study was to provide a more complete understanding of agility-related injuries in competition-level agility dogs. The first specific objective was to describe agility-related injuries in Finnish competition-level agility dogs. The second objective was to provide information on training, competition, and management of agility dogs prior to the injury. Our last objective was to examine risk factors for agility-related injury. Based on previous studies and anecdotal evidence, we hypothesized that previous musculoskeletal injuries, increased training and competition frequency, and higher competition speed are associated with increased odds for agility-related injury during one calendar year, 2019.

2. Materials and Methods

2.1. Dogs and Respondents

Finnish owners and handlers whose competing agility dogs actively participated in agility and had had at least one agility-related injury during 2019 were included in this study. The dog had to have trained agility during 2019 and competed in Finland in 2018 and/or 2019. Injury was defined as an agility-caused clinical sign, evident within 24 h of sports performance, resulting in restriction of normal exercise and training. If the dog had suffered multiple injuries during 2019, only the latest one was described. The survey was completed by the owner or handler once per dog. If two surveys were sent in for the same dog, identified by the dog's registration number, only the earlier answers were included. One respondent was allowed to complete the survey for multiple dogs. Data from non-injured dogs, collected by the same survey and published elsewhere [6], were compared with data from injured dogs in the risk factor analysis. The survey was distributed through the Finnish Agility Association and using social media (multiple Facebook pages). It was open to participation from July to September 2020.

2.2. Questionnaire

A Finnish language retrospective online survey consisting mainly of close-ended multiple-choice questions was developed using expert opinions, cognitive interviews, check lists, and a test group. The development of the questionnaire is described elsewhere [6]. The final survey (File S1) utilized skip logic, with only applicable questions shown to each respondent.

The questionnaire contained questions about signalment, the dog's and the main handler's experience in agility, and the health history of the dog. Moreover, questions dealt with the context of the injury, description of the injury, treatments used, and time to recovery (Table 1). Training practices and musculoskeletal care prior to the injury were also covered.

Table 1. Injury-related variables provided by the survey.

Category	Variable
Injury	Agility-related injury during 2019 (yes/no) Number of agility-related injuries during 2019 Date of the latest agility-related injury
Context of the injury	During competition or training If training: first or second half of the training session If competition: number of runs before the injury on that day During obstacle performance (yes/no) [1] If obstacle-associated: Which obstacle, collision (yes/no), fall (yes/no), slipping during obstacle performance (yes/no) Slipping in between obstacles (yes/no) When injury was noticed (during or after agility) Surface of the agility field
Description of the injury	Anatomical location [2] Type of the injury Clinical signs
Treatment	Veterinary care (yes/no) If veterinary care was sought: the time of diagnosis in relation to injury Treatments
Recovery	Recovery time to normal exercise Recovery time to performance level prior to injury

[1] Including take-off to and landing from the obstacle. [2] Picture describing the following anatomical locations was provided for respondents: Head, eye, neck, back, pelvis, tail, rib cage, scapula, shoulder, brachium, elbow, antebrachium, carpus, metacarpal region, toe or nail (front limb), paw pads (front limb), thigh, groin, stifle, crus/shank, hock, metatarsal region, toe or nail (hind limb), and paw pads (hind limb).

Background information was collected for both injured and non-injured dogs and consisted of variables such as age, size, highest competition level of the dog and handler, and previous diagnoses of musculoskeletal diseases, as earlier described in Part I of the study [6]. Training- and management-related items included for example frequency of training sessions, field surfaces, warm-up routine, musculoskeletal care, and exercise [6]. For dogs with an agility-related injury, questions covered training and management three months prior to the injury but were otherwise the same as in Part I of the study [6]. Musculoskeletal care was an exception to this, as practices one year prior to the injury were queried.

2.3. Competition Result Database

The Finnish Agility Association's competition result database was used to retrieve information on each dog's competition frequency during a three-month period prior to the injury. Additionally, the competition speed of the dog (mean speed of faultless runs) and the proportion of faultless runs were retrieved from the database and combined with the survey answers. Competition runs from both 2018 and 2019 were used to attain information on competition speed and proportion of faultless runs for as many dogs as possible.

2.4. Data Curation

In case of inconsistent answers, respondents were contacted by email. Answers were corrected according to email replies and open field descriptions.

Handling of the variables of age, competition years in agility, weight/height ratio, and health history was performed as previously described [6]. If the date of diagnosis of patellar luxation, osteochondritis dissecans (OCD), injury of the biceps tendon or muscle, injury of the supraspinatus muscle or tendon, shoulder instability/medial shoulder syndrome, fracture, other muscle injury, carpal sprain or sprain of a toe was not available, the information was considered missing. Only diagnoses made prior to 2019 were included to ensure these possible predisposing conditions had been present before the agility-related injury of 2019.

The anatomical locations of toe and nail were presented as a combined option in the survey but were handled separately using details from the open field descriptions and email replies. In cases where the respondent had selected almost all or all front limb locations, the exact location of the injury was considered ambiguous. Therefore, another anatomical location, "unspecified front limb site", was added during data curation for these dogs.

For comparison of training-related routines of injured and non-injured dogs, some variables were categorized into fewer categories: Frequency of training sessions (<2, 2, or >2 sessions/week), training session length (up to 10 min, 10–15 min, at least 15 min) number of competition runs per month (<1.5, 1.5–<3.0, $\geq$3.0), main field surface during training and competitions (dirt/sand, artificial turf without filling, artificial turf with rubber filling, artificial turf with cork filling, or other), field surface during injury (as for main surface), and number of previous agility-related injuries (0, 1, or $\geq$2). To evaluate risk of collision with obstacle, the following three obstacle categories were created: jump obstacles (bar jump, spread jump, long jump, tire, and wall), contact obstacles (dogwalk, A-frame, and seesaw), and open tunnel and/or weave poles. Performance of each obstacle is shown in Video S1.

In non-injured dogs, training session frequency and length and main field surface were collected separately for winter and summer seasons [6]. To allow comparison with injured dogs, for non-injured dogs the answers of summer and winter season were combined, and only non-injured dogs with one categorized value for each of these variables (e.g., same frequency of training sessions during winter and summer seasons—or the dog had trained only during one season) were included in the risk factor analyses of each of these factors.

Sample size varied for each variable due to the skip logic and because "I don't know" or "I can't remember" answers were handled as missing values.

2.5. Data Analysis and Statistical Methods

A power analysis was utilized to calculate the sample size required to detect increased odds for injury during 2019, with a power of 80% and a confidence level of 95%, for the following parameters: (1) Mean competition speed of the dog (to detect a 0.2 m/s difference between injured and non-injured dogs, and (2) number of competition runs per month (to detect a difference of 0.5 runs per month). Data from previous studies were used to estimate injury rate [2,4]. To calculate means +/− SDs of speed and number of competition runs, results from the Finnish Agility Associations competition result database were used. The total number of required dogs (injured and non-injured summed) was 594 for competition speed and 251 for competition runs. However, all responses received during the data collection period were included and sample size was mainly dictated by available data.

Descriptive statistics (median and interquartile range for continuous variable, frequency tables for categorial variables) were calculated for all variables. Multivariate logistic regression analysis was used to evaluate whether an obstacle category and/or competition speed of the dog was associated with an obstacle collision. The same analysis approach was also used to investigate whether a field surface or obstacle category was associated with slipping during obstacle performance, and to investigate the association of field surface and competition speed with slipping elsewhere than during obstacle performance.

Potential risk factors for injury included all variables on background information, and training, competition, and exercise, with the exception of time off from agility, as reported in Part I of the study [6]. Time off from agility was not evaluated as a potential risk factor, as the values were not comparable due to differing time frames in injured (3 months) and non-injured dogs (one year). Training, competition, and management routines of injured dogs per year (musculoskeletal care) or per three months (all other variables) prior to their injury were compared with those of non-injured dogs during the year 2019.

Each factor was first evaluated using a univariate logistic regression, where each potential risk factor was assessed separately. Variables significant in univariate regression with $p < 0.1$ were included in the development of a multivariate model.

Second, to control for confounders, a penalized least absolute shrinkage and selection operator (LASSO) logistic regression model was fitted. LASSO is a regression analysis method that performs both variable selection and regularization to enhance the prediction accuracy and interpretability of the fitted statistical model. Akaike information criteria (AIC) was used as the criteria for optimal model selection, and Nesterov optimization as the optimization technique. The risk factors included in the optimal model were then used to fit a multivariate logistic regression model. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated from the model. Interactions between the risk factors were not evaluated.

Significance was set at $p < 0.05$. Statistical analyses were done using SPSS (version 26, IBM Corp., Armonk, NY, USA) and SAS (version 9.4, SAS Institute Inc., Cary, NC, USA).

3. Results

Continuous variables are presented as median (interquartile range). The total number of dogs varied between variables as a result of the skip logic and missing values.

3.1. Dogs and Respondents

Survey data from 864 competition-level agility dogs were used to complete this study (Figure 1). The following paragraphs describe the agility-related injuries and injury preceding training, competition, and management routines of the 119 injured dogs provided by 117 respondents. Training, competition, and management routines of dogs without agility-related injury during 2019 (n = 745) have been described elsewhere [6], but they were used here to investigate which factors were associated with risk for agility-related injury during 2019.

The age of the dogs at the beginning of 2019 was 4.9 years (3.3–6.7 years). Weight and height were 15.0 kg (10.0–20.0 kg) and 48.0 cm (39.0–53.0 cm), respectively. Dogs represented the following height categories [12]: Extra Small (7.6%; height at withers <28 cm), Small (10.9%; 28 cm to <35 cm), Medium (20.2%; 35 cm to <43 cm), Small Large (26.1%, 43 cm to <50 cm), and Large (35.3%, ≥50 cm).

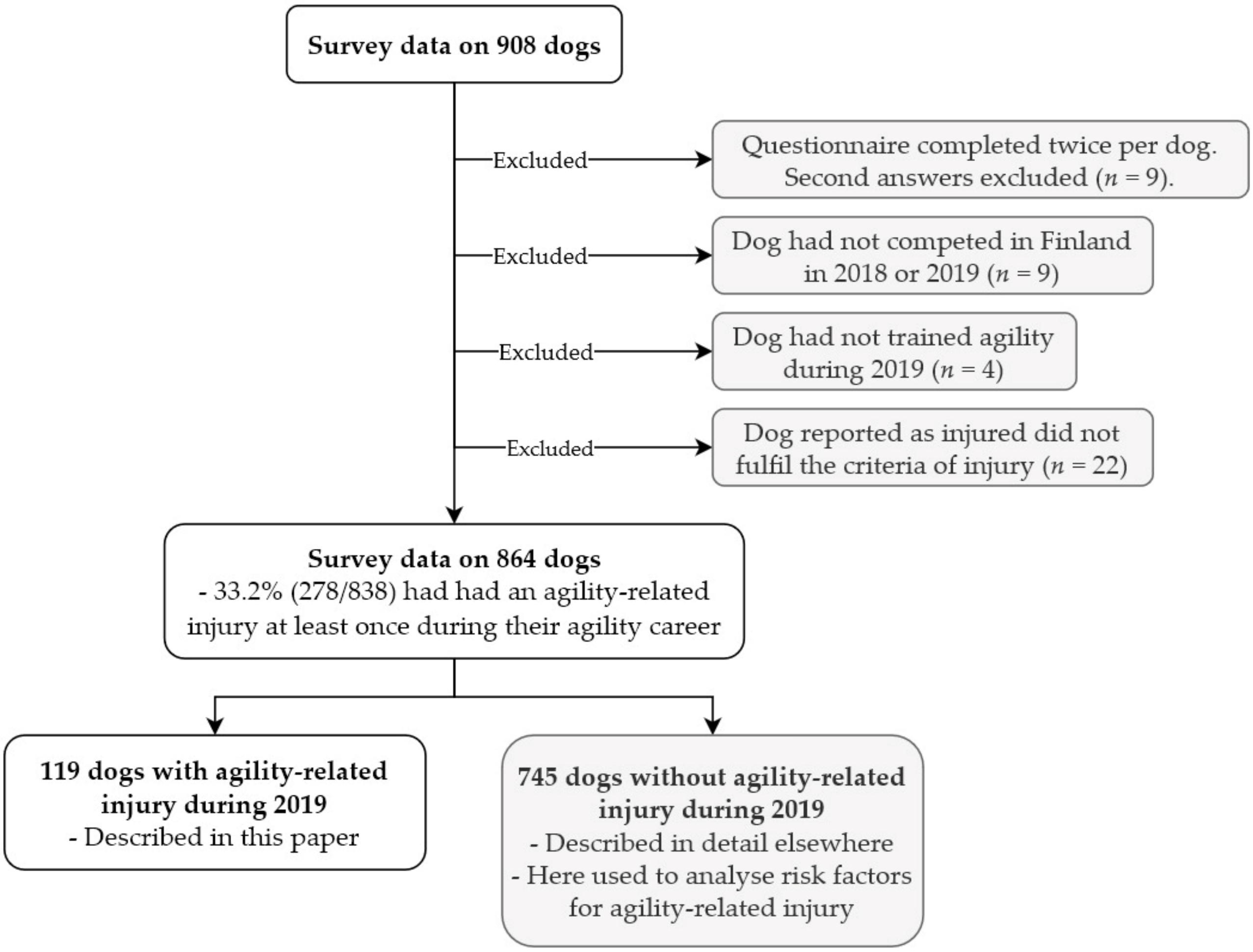

Figure 1. Dogs included in this study.

Of the sample of 119 dogs, 26.9% were intact females, 23.5% spayed females, 34.5% intact males, and 15.1% neutered males. Injuries were reported for dogs of 39 breeds. The most commonly injured breed was Border Collie (23.5%; 28/119). Table S1 provides the breeds of all injured dogs.

Dog's and Main Handler's Experience in Agility

The age when dogs had started course-like training (sequences of at least five obstacles) was 1.0 years (0.8–1.5 years, n = 115). Jumps were set at competition height at the age of 1.5 years (1.3–2.0 years, n = 116). Dogs had started competing in agility at the age of 2.3 years (1.8–3.0 years, n = 119). At the end of 2019, the length of the competition career was 3.1 years (1.6–5.0 years, n = 119). The dogs (n = 119) had the following highest competition levels from lowest to highest [6]: class 1 (20.2%), class 2 (16.8%), class 3 (31.1%), national championships (29.4%), and national team (2.5%).

The dogs' main handlers had 10.0 years of experience in agility (6.0–15.0 years, n = 117). Almost half of the main handlers (43.6%; 51/117) had competed in national championships, or 3.4% (4/117) had been part of the national team. The highest competition level of the remaining handlers was class 1 (11.1%; 13/117), class 2 (11.1%; 13/117), or class 3 (30.8%; 36/117).

3.2. Context of the Injury

Most dogs (72.3%; 86/119) had had only one agility-related injury during 2019, with the number of agility-related injuries that year ranging between one and six for a single dog. The latest injury of 2019 will be described in the following sections.

3.2.1. Training- and Competition-Related Injuries

About two-thirds (66.9%; 79/118) of the reported injuries occurred during training, while almost one-third (33.1%; 39/118) occurred during competition. Of the training-related injuries, 71.7% (33/46) occurred during the second half of the training session. When considering all runs during 2019 of the 864 dogs, the incidence of competition-related injury was 1.44/1000 competition runs. Completed competition runs during the same day prior to the competition-related injury ranged from zero to three (Table 2). In 62.3% (71/114) of the dogs, the injury was recognized only after agility, with the remaining cases (37.7%; 43/114) noticed during the agility session.

Table 2. Number of completed runs prior to competition-related injury (n = 34).

Number of Runs	Number of Dogs	Proportion of Dogs with Competition-Related Injury
0	8/34	23.5%
1	16/34	47.1%
2	5/34	14.7%
3	5/34	14.7%

3.2.2. Obstacle-Related Injuries

Most injuries occurred during obstacle performance (56.8%; 67/118). Some dogs (13.6%; 16/118) were moving between obstacles when injured, and in 4.2% (5/118) of the dogs the injury occurred in some other agility-related situation, such as at start line or during rewarding. The situation around the injury was unknown in 28.8% (34/118) of the dogs. Multiple options of injury-related factors had been chosen for four dogs. Table 3 shows the obstacles associated with injuries during obstacle performance. No injuries were associated with the flat tunnel or the wall jump.

Table 3. Obstacles involved in injuries of 63 dogs. Performance of each obstacle is presented in Video S1.

Obstacle	Number of Dogs	Proportion of Dogs with Obstacle-Related Injury
Bar jump	23/63	36.5%
Dogwalk	11/63	17.5%
A-frame	10/63	15.9%
Open tunnel	10/63	15.9%
Weave poles	4/63	6.3%
Seesaw	2/63	3.2%
Spread jump	1/63	1.6%
Tire	1/63	1.6%
Long jump	1/63	1.6%

Roughly a third (29.9%, 20/67) of the obstacle-related injuries resulted from a collision with an obstacle. Collision was associated with the three obstacle categories created (p = 0.001, n = 52); the odds of collision were decreased for contact obstacles (OR 0.03, 95% CI 0.00–0.30, p = 0.003), and open tunnel and/or weave poles (OR 0.05, 95% CI 0.01–0.43, p = 0.007) compared with jump obstacles. In the same regression model, competition speed was not associated with collisions (p = 0.547).

Of obstacle-related injuries, slipping during obstacle performance had occurred in 42.3% (22/52) of dogs. Obstacle category was associated with slipping during obstacle performance (p = 0.012, n = 46), with decreased odds of slipping during contact obstacles (OR 0.08, 95% CI 0.01–0.86, p = 0.037) compared with jump obstacles. Injury during open tunnels and/or weaves did not significantly differ from jump obstacles in the risk for slipping during obstacle performance (p = 0.143), and field surface was not associated with slipping in the same regression model (p = 0.517). Slipping elsewhere than during obstacle performance was reported in 16.7% (15/90) of dogs. Neither competition speed (p = 0.827) nor field surface (p = 0.323) was associated with slipping elsewhere than during obstacle performance.

Most dogs (72.7%; 8/11) with dogwalk-associated injury fell from the obstacle. Of dogs with an A-frame-associated injury, 40.0% (4/10) fell from the obstacle. Dogs with dogwalk-associated injuries performed the obstacle using the following techniques: stopped contact (60.0%; 6/10), running contact (30.0%; 3/10), or other or in between (10.0%; 1/10). All dogs (100.0%; 9/9) with an A-frame -associated injury used the running contact technique. Regarding performance technique, two dogs were excluded from the analysis because of inconsistent answers.

3.2.3. Field Surface

Two-thirds (67.6%; 75/111) of the dogs injured themselves on a familiar surface on which they had trained or competed on a weekly basis during the three-month period prior to the injury. Table 4 shows field surfaces on which the injuries occurred.

Table 4. Field surfaces at the time of injury (n = 111).

Field Surface	Number of Dogs	Proportion of Dogs
Artificial turf with rubber filling	39/111	35.1%
Dirt or sand	25/111	22.5%
Artificial turf without filling	21/111	18.9%
Artificial turf with cork filling	14/111	12.6%
Artificial turf with sand filling	6/111	5.4%
Natural grass	5/111	4.5%
Rubber mat	1/111	0.9%

3.3. Description of Injury

3.3.1. Anatomical Location

The front limb was injured in 60.5% (72/119), neck or trunk in 34.5% (41/119), and the hind limb in 19.3% (23/119) of dogs. The most commonly injured anatomical locations are listed in Table 5. Additional injured anatomical locations included paw pad (front limb) (5.9%; 7/119), other location (5.9%; 7/119), digit (hind limb) (5.0%; 6/119), head (4.2%; 5/119), groin (4.2%; 5/119), metacarpal region (4.2%; 5/119), unspecified front limb site (3.4%; 4/119), stifle (3.4%; 4/119), elbow (2.5%; 3/119), antebrachium (2.5%; 3/119), and unknown (2.5%; 3/119). One injury (0.8%) was reported for each of the following: tail, hock, metatarsal region, crus, and nail of a hind limb. Multiple sites were reported for 37.8% (45/119) of the dogs.

Table 5. Most commonly injured anatomical locations (n = 119).

Anatomical Location	Number of Dogs	Proportion of Dogs
Back	23/119	19.3%
Brachium	19/119	16.0%
Scapular region	16/119	13.4%
Shoulder	15/119	12.6%
Pelvis	14/119	11.8%
Thigh	13/119	10.9%
Ribcage	12/119	10.1%
Digit (front limb)	12/119	10.1%
Carpus	11/119	9.2%
Nail of a front limb	11/119	9.2%
Neck	10/119	8.4%

No injuries to eye, paw pads of hind limbs, or abdominal region were reported.

3.3.2. Type of Injury

Respondent-defined injury types in the order of incidence were muscle strain (42.0%; 50/119), unclear to respondent (18.5%; 22/119), ligament sprain (17.6%; 21/119), other (14.3%; 17/119), torn nail (10.1%; 12/119), abrasion (5.0%; 6/119), contusion (3.4%; 4/119), fracture (2.5%; 3/119), and laceration (1.7%; 2/119). Multiple types of injuries were reported for 11.0% (13/119) of dogs. Puncture wounds or dislocated joints were not reported.

3.3.3. Clinical Signs

Lameness was the most common clinical sign (64.8%; 70/108), followed by pain on palpation or during passive range of motion assessment of joints (49.1%; 53/108), decreased weight bearing of a limb during standing (32.4%; 35/108), restricted range of motion in a limb and/or the trunk (30.6%; 33/108), stiff gait or stiffness when getting up (28.7%; 31/108), impaired performance (23.1%; 25/108), wound or bleeding (13.0%; 14/108), swelling (10.2%; 11/108), heat at injured area (10.2%; 11/108), or abnormal posture of a limb or trunk (5.6%; 6/108). Another clinical sign, such as restlessness or unwillingness to jump into the car, was present in 10.2% (11/108) of dogs. Multiple different clinical signs, ranging from two to seven, were reported in 77.8% (84/108) of dogs.

3.3.4. Treatment and Recovery

Veterinary care was sought for 41.2% (49/119) of dogs due to their above-described injuries. The duration from injury to veterinary diagnosis was four days (one to 36 days). Therapies and paraprofessionals used in the treatment are listed in Table 6. Multiple treatment options were chosen in 76.3% (90/118) of the dogs. No treatment was given to 1.7% (2/118) of the dogs.

Table 6. Therapies and paraprofessionals used in treatment of agility-related injuries (n = 118).

Treatment	Number of Dogs	Proportion of Dogs
Exercise restriction	91/118	77.1%
Medical treatment	55/118	46.6%
Physiotherapy	50/118	42.4%
Rehabilitation/conditioning as part of physiotherapy	25/118	21.2%
Osteopathy	15/118	12.7%
Massage	14/118	11.9%
Laser therapy	13/118	11.0%
Wound care	11/118	9.3%
Other therapies [1]	9/118	7.6%
Taping	8/118	6.8%
Acupuncture	8/118	6.8%
Surgery	6/118	5.1%
Craniosacral therapy	5/118	4.2%
Splint or cast	4/118	3.4%
Cryotherapy	4/118	3.4%

[1] Other therapies included, for example, myofascial therapy (n = 3) and magnet therapy (n = 1).

Recovery to normal daily exercise took 14 days (7–37 days, n = 114). Recovery to previous level in agility took 28 days (14–70 days, n = 88). Injury led to retirement from agility for 9.6% (11/114) of the dogs. Information regarding severity of injury was available for 99 dogs and is presented in Table 7.

Table 7. Severity of the injury graded by recovery time to previous level in agility (*n* = 99).

Severity	Number of Dogs	Proportion of Dogs
Minor (<3 weeks)	26/99	26.3%
Moderate (3 to <8 weeks)	29/99	29.3%
Severe (≥8 weeks, with return to agility)	33/99	33.3%
Career ending	11/99	11.1%

3.4. Training, Competition, and Management Prior to Injury

3.4.1. Agility Training

During the three months preceding the injury, the number of weekly training sessions ranged from less than one to seven. Most dogs trained one (35.6%; 42/118), two (41.5%; 49/118), or three (12.7%; 15/118) times per week. Typically, the active training time during one session was 5–10 min (18.6%; 22/118), 10–15 min (51.7%; 61/118), or 15–20 min (25.4%; 30/118). Weekly total training time was 18 min (13–25 min; *n* = 118) during weeks that the dog participated in agility. The usual relative jump height at training was 90% (77–98%; *n* = 118) of a dog's height at withers.

The A-frame was performed using the following performance techniques: running contact (59.6%; 65/109), stopped contact (35.8%; 39/109), or other (4.6%; 5/109). The dogwalk was performed using the following performance techniques: stopped contact (53.6%; 59/110), running contact (40.0%; 44/110), or other (6.4%; 7/110).

3.4.2. Competition

Dogs competed a median of three competition runs per month (0.7–5.0 runs per month; *n* = 119) during the three-month period prior to the injury. During 2018 and 2019 the competition speed of faultless runs was 4.6 m/s (4.0–4.9 m/s; *n* = 104), and the proportion of faultless runs was 16% (5–25%; *n* = 119). The maximum relative fence height in competitions was 103% (95–109%; *n* = 118) of the dog's height at withers. Amount of weekly agility, combining training and competition, was 19 min (13–27 min; *n* = 112) during the weeks that the dog participated in agility.

3.4.3. Field Surface

The main surfaces used in training and competition during the preceding three months included artificial turf with rubber (32.5%; 38/117), dirt or sand (26.5%; 31/117), artificial turf without filling (21.4%; 25/117), artificial turf with cork filling (12.0%; 14/117), artificial turf with sand filling (2.6%; 3/117), natural grass (1.7%; 2/117), fiber-sand mix (1.7%; 2/117), rubber mat (0.8%; 1/117), and horse-riding surface (0.8%; 1/117).

3.4.4. Time off from Agility

During the three months preceding injury, 18.6% (22/118) of dogs had had time off from agility, with a total duration of 3.5 weeks (2.8–5.3 weeks; *n* = 18). The reasons for the break were planned break (e.g., periodization of training) (50.0%; 11/22), reason unrelated to the dog (27.2%; 6/22), previous injury or illness of the dog (22.7%; 5/22), or other dog-related reason (4.5%; 1/22). One dog had two reasons for a break.

3.4.5. Warm-up and Cool-down Routines

Warm-up before agility was performed either always (95.8%; 113/118) or usually (4.2%; 5/118). The usual duration of the warm-up ranged from 5 min to more than half an hour—5–10 min (10.2%; 12/118), 10–15 min (28.0%; 33/118), 15–20 min (32.2%; 38/118), 20–25 min (16.1%; 19/118), 25–30 min (11.9%; 14/118), and over 30 min (1.7%; 2/118). Cool-down was performed always (88.1%; 104/118), usually (10.2%; 12/118), or sometimes (1.7%; 2/118). The usual duration of the cool-down ranged from less than 5 min to more than half an hour—below 5 min (0.8%; 1/118), 5–10 min (10.2%; 12/118), 10–15 min (22.9%;

27/118), 15–20 min (28.8%; 34/118), 20–25 min (16.1%; 19/118), 25–30 min (15.3%; 18/118), and over 30 min (5.9%; 7/118).

Table 8 shows the elements of a usual warm-up and cool-down. The respondents were able to select multiple items. The number of chosen items for the warm-up ranged from one to 11, with multiple items chosen for 96.6% (114/118) of dogs. For the cool-down, the number of chosen items ranged from zero to eight, with multiple choices reported for 90.0% (105/118) of the dogs.

Table 8. Elements of a usual warm-up and cool-down.

Item	Warm-Up (*n* = 118)	Cool-Down (*n* = 118)
Exercising on leash	93.2% (*n* = 110/118)	92.4% (109/118)
Exercising off leash	61.0% (*n* = 72/118)	55.9% (66/118)
Walking	61.9% (*n* = 73/118)	70.3% (83/118)
Running	72.9% (*n* = 86/118)	50.8% (60/118)
Sprinting	35.6% (*n* = 42/118)	1.7% (2/118)
Tricks	69.5% (*n* = 82/118)	4.2% (5/118)
Tug play	31.4% (*n* = 37/118)	2.5% (3/118)
Active stretches	31.4% (*n* = 37/118)	4.2% (5/118)
Passive stretches	13.6% (*n* = 16/118)	10.2% (12/118)
Habituation to the field surface	32.2% (*n* = 38/118)	Not applicable
Obstacle performances as part of warm-up	20.3% (*n* = 24/118)	Not applicable
Other [1]	1.7% (*n* = 2/118)	3.4% (4/118)

[1] Other elements included, for example, playing with other dogs, massage, or swimming.

3.4.6. Musculoskeletal Care and Conditioning

The frequency of visits to professionals for musculoskeletal care is presented in Table 9. Most dogs (78.8%; 93/118) visited physiotherapist, massage therapist, osteopath. or other professional at least once every three months during the year preceding the injury. Conditioning exercises were performed by 78.8% (93/118) of dogs during the three-month period prior to injury. These exercises were done at least two times a week (18.3%; 17/93), once a week to every two weeks (44.1%; 41/93), or less often than every two weeks (37.6%; 35/93). Conditioning exercises were typically planned by the owner or handler (61.3%; 57/93), followed by the physiotherapist (30.1%; 28/93) and other persons (8.6%; 8/93).

Table 9. Distribution of treatment frequency of 118 dogs by massage therapist, physiotherapist, osteopath, or other professional during the year preceding injury.

Professional	At Least Once a Month	Every Two to Three Months	Less Often	Not at All
Massage therapist	16.1% (*n* = 19/118)	30.5% (*n* = 36/118)	19.5% (*n* = 23/118)	33.9% (*n* = 40/118)
Physiotherapist	6.8% (*n* = 8/118)	31.4% (*n* = 37/118)	27.1% (*n* = 32/118)	34.7% (*n* = 41/118)
Osteopath	1.7% (*n* = 2/118)	14.4% (*n* = 17/118)	20.3% (*n* = 24/118)	63.6% (*n* = 75/118)
Other	1.7% (*n* = 2/118)	16.1% (*n* = 19/118)	9.3% (*n* = 11/118)	72.9% (*n* = 86/118)

3.4.7. Daily Exercise

Total duration of usual daily walks was 1.5 h (1.3–2.0 h; *n* = 112) during the three-month period prior to the injury. During walks 4.2% (5/118) of dogs were always off leash, 46.6% (55/118) mostly off leash, 46.6% (55/118) mostly on leash, and 2.5% (3/118) always on leash. Besides agility, 12.7% (15/118) participated in other physically demanding activities such as canicross, herding, or hunting.

3.5. Health History

Most dogs (57.9%; 66/114) with agility-related injury during 2019 had suffered another agility-related injury prior to the latest injury of 2019. For 60 of these dogs, the number of previous agility-related injuries was known; the median of previous injuries was two (two to four injuries). Non-agility-related musculoskeletal injuries had occurred to 39.8% (45/113) of dogs during their lifetime.

Table 10 shows frequency of selected musculoskeletal diagnoses unrelated to the agility-related injury of 2019. Diagnoses of hip dysplasia, lumbosacral transitional vertebra or disease of the elbow were included regardless of the date of diagnosis, as these conditions are considered chronic. Other diseases were included as possible predisposing factors if they had been diagnosed before 2019. Diagnoses of iliopsoas injury, spondylosis, osteoarthritis, intervertebral disc disease, cranial cruciate tear, or luxation of the superficial digital flexor tendon were not reported by the respondents.

Table 10. Musculoskeletal diagnoses unrelated to the agility-related injury of 2019.

Diagnosis	Number of Dogs	Proportion of Dogs
Lumbosacral transitional vertebra	26/119	21.8%
Hip dysplasia	16/119	13.4%
Other muscle injury	5/116	4.3%
Fracture	5/119	4.2%
Patellar luxation	4/119	3.4%
Disease of the elbow	3/119	2.5%
Carpal sprain	2/118	1.7%
Sprain of toe	2/118	1.7%
Injury of biceps tendon or muscle	2/118	1.7%
Other tendon injury	2/118	1.7%
Osteochondrosis/osteochondritis dissecans	2/119	1.7%
Injury of supraspinatus muscle or tendon	1/118	0.8%
Shoulder instability/medial shoulder syndrome	1/119	0.8%

Of the 26 dogs with lumbosacral transitional vertebra, 76.9% had LTV1 (separation of first spinous process from the median crest of the sacrum or other mildly abnormal structure), 7.7% LTV2 (symmetrical LTV), 7.7% LTV3 (asymmetrical LTV), and 7.7% LTV4 (six or eight lumbar vertebrae).

3.6. Potential Risk Factors for Agility-Related Injury during 2019

Univariate regression analysis revealed 27 variables associated with increased or decreased odds of agility-related injury during 2019 with $p < 0.1$ (Table S2). These variables were selected for the development of a multivariate logistic regression model. Height category and previous agility-related injury (yes/no) were removed from the multivariate analysis since they were closely related to height and number of previous agility-related injuries, respectively.

Only dogs without missing data on any variables can be included in the development of the multivariate regression model. Due to the small sample size for the variables of frequency of training sessions, competition speed, and field surface variables, they were analyzed in separate subgroup models and were not included in the model for the full data. A small number of extreme (high) outliers were detected for three variables, and thus, the highest values were pooled so that these extreme outliers were not overemphasized in the statistical modelling results: weight (≥31 kg = 31 kg, $n = 7$), age at which course-like training was started (≥3.17 years = 3.17 years, $n = 18$), and age at which jumps were set at competition height (≥3.5 years = 3.5 years, $n = 18$).

The final multivariate model is shown in Figure 2. Subgroup models used all variables that were used for development of the final model, and additionally either frequency of training sessions (Figure 3), field surface at the time of injury and main field surface in training and competitions (Figure 4), or competition speed (Figure 5). Significant risk factors for agility-related injury during 2019 included multiple previous agility-related injuries, diagnosis of lumbosacral transitional vertebra, older age when starting course-like training, physiotherapy every two to three months compared with never, and more than two agility training sessions per week. Significant protective factors included moderate competition frequency, an A-frame performance technique other than stopped or running contact, and, in one model, participation in other physically demanding sports. Competition speed or field surface variables were not included in the speed model or the field surface model, respectively.

The anecdotal assumption being that starting training at a young age increases odds of injury, additional univariate logistic regression analysis was done to evaluate association between age at which course-like training was started and agility-related injury during the whole career (during 2019 or earlier). No association was observed ($p = 0.919$).

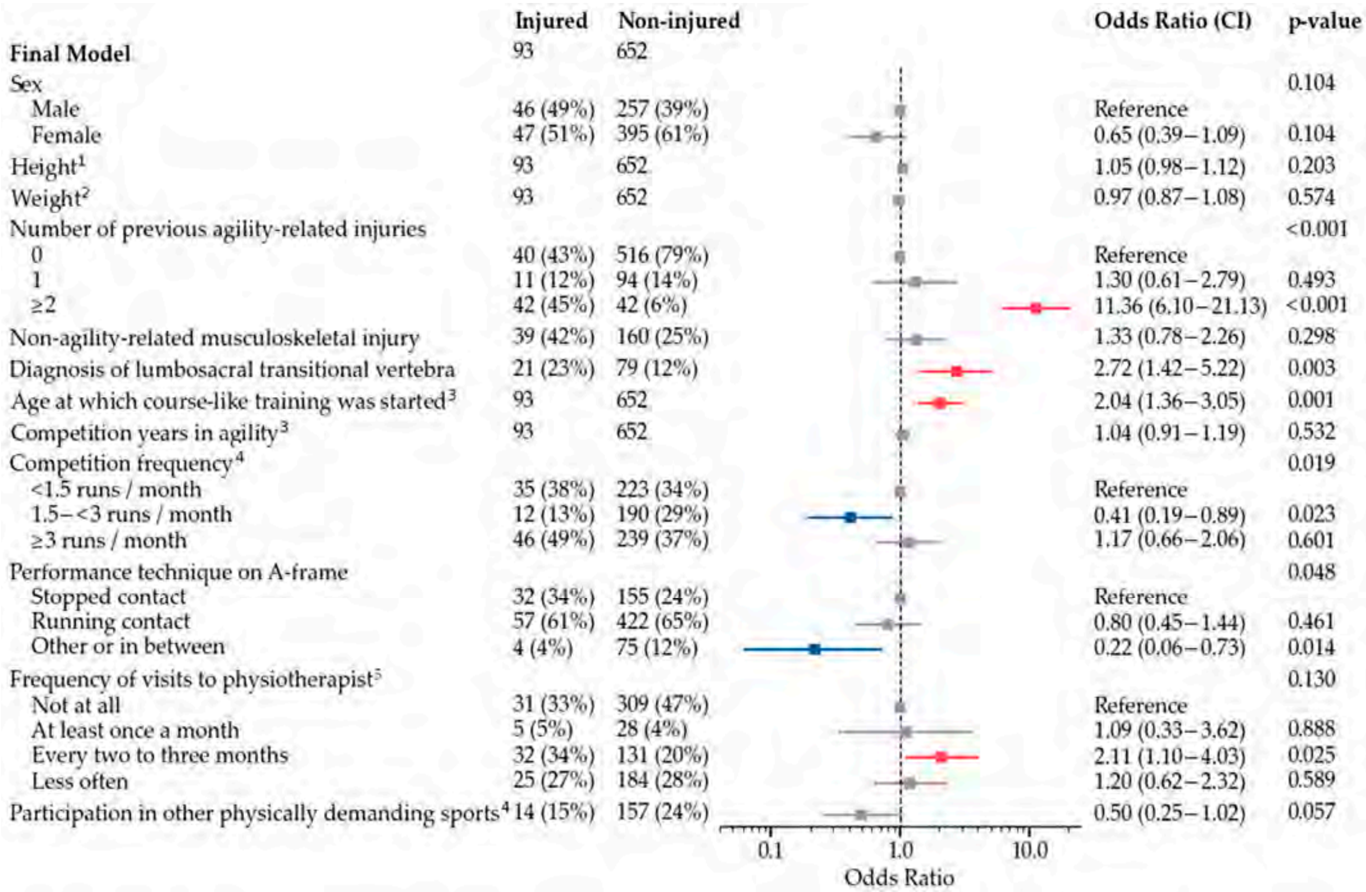

Figure 2. Training frequency model for odds of agility-related injury during 2019. [1] For a one centimeter increase, the odds increase by OR. [2] For a one year increase, the odds increase by OR. [3] For a one year increase, the odds increase by OR. [4] Routines during the three-month period preceding injury in injured dogs and during 2019 in non-injured dogs. [5] Routines during the one-year period preceding injury in injured dogs and during 2019 in non-injured dogs.

	Injured	Non-injured	Odds Ratio (CI)	p-value
Training Frequency Model	93	485		
Age (years)	93	485	1.11 (0.96–1.29)	0.151
Sex				0.104
Male	46 (49%)	192 (40%)	Reference	
Female	47 (51%)	293 (60%)	0.87 (0.40–1.17)	0.167
Height[1]	93	485	1.03 (1.00–1.06)	0.091
Number of previous agility-related injuries				<0.001
0	40 (43%)	385 (79%)	Reference	
1	11 (12%)	67 (14%)	1.09 (0.48–2.48)	0.823
≥2	42 (45%)	33 (7%)	9.14 (4.66–17.93)	<0.001
Non-agility-related musculoskeletal injury	39 (42%)	117 (24%)	1.39 (0.78–2.48)	0.266
Diagnosis of lumbosacral transitional vertebra	21 (23%)	55 (11%)	3.14 (1.55–6.38)	0.002
Age at which course-like training was started[2]	93	485	1.80 (1.23–2.88)	0.014
Frequency of training sessions[3]				0.005
<2 sessions / week	40 (43%)	267 (55%)	Reference	
2 sessions / week	39 (42%)	188 (39%)	1.43 (0.78–2.64)	0.253
>2 sessions / week	14 (15%)	30 (6%)	4.67 (1.85–11.82)	0.001
Competition frequency[3]				0.055
<1.5 runs / month	35 (38%)	180 (37%)	Reference	
1.5–<3 runs / month	12 (13%)	130 (27%)	0.49 (0.22–1.12)	0.089
≥3 runs / month	46 (49%)	175 (36%)	1.30 (0.71–2.38)	0.393
Performance technique on A-frame				0.026
Stopped contact	32 (34%)	126 (26%)	Reference	
Running contact	57 (61%)	297 (61%)	0.82 (0.44–1.52)	0.522
Other or in between	4 (4%)	62 (13%)	0.17 (0.05–0.61)	0.007
Frequency of visits to physiotherapist[4]				0.095
Not at all	31 (33%)	237 (49%)	Reference	
At least once a month	5 (5%)	18 (4%)	1.07 (0.28–4.03)	0.925
Every two to three months	32 (34%)	99 (20%)	2.30 (1.15–4.61)	0.018
Less often	25 (27%)	131 (27%)	1.14 (0.57–2.29)	0.704
Frequency of visits to other professionals[4]				0.235
Not at all	68 (73%)	410 (85%)	Reference	
At least once a month	1 (1%)	20 (4%)	0.46 (0.05–3.87)	0.474
Every two to three months	14 (15%)	31 (6%)	1.88 (0.79–4.48)	0.155
Less often	10 (11%)	24 (5%)	2.19 (0.75–6.37)	0.15
Participation in other physically demanding sports[3]	14 (15%)	110 (23%)	0.56 (0.27–1.17)	0.125

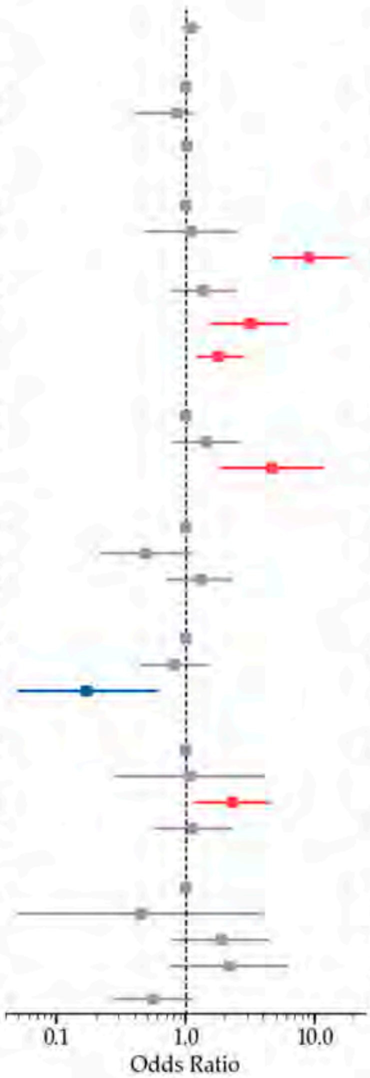

Figure 3. Training frequency model for odds of agility-related injury during 2019. [1] For a one centimeter increase, the odds increase by OR. [2] For a one year increase, the odds increase by OR. [3] Routines during the three-month period preceding injury in injured dogs and during 2019 in non-injured dogs. [4] Routines during the one-year period preceding injury in injured dogs and during 2019 in non-injured dogs.

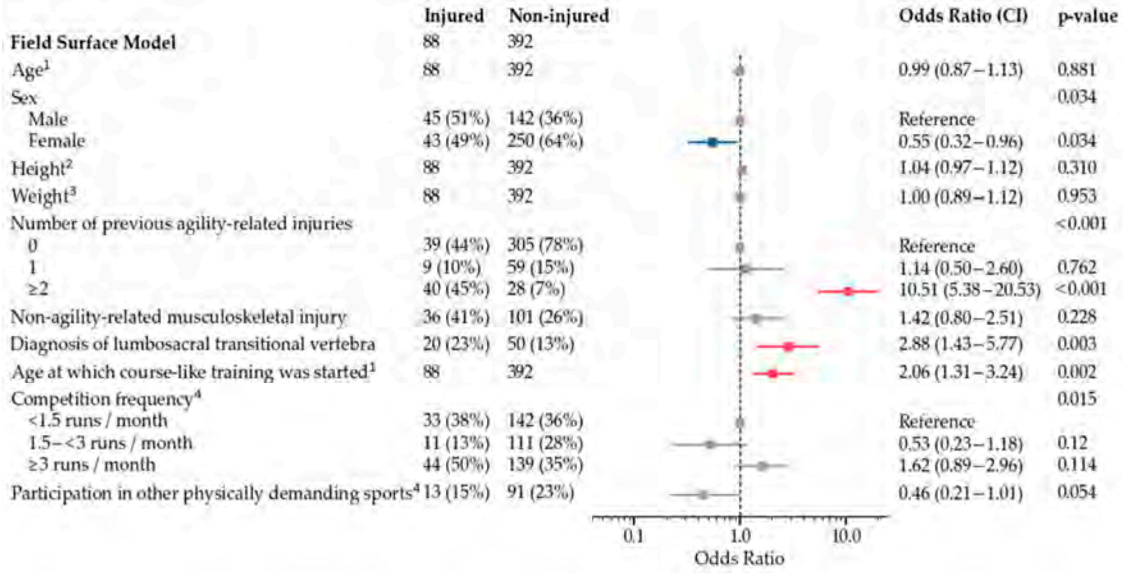

Figure 4. Field surface model for odds of agility-related injury during 2019. [1] For a one year increase, the odds increase by OR. [2] For a one centimeter increase, the odds increase by OR. [3] For a one kilogram increase, the odds increase by OR. [4] Routines during the three-month period preceding injury in injured dogs and during 2019 in non-injured dogs.

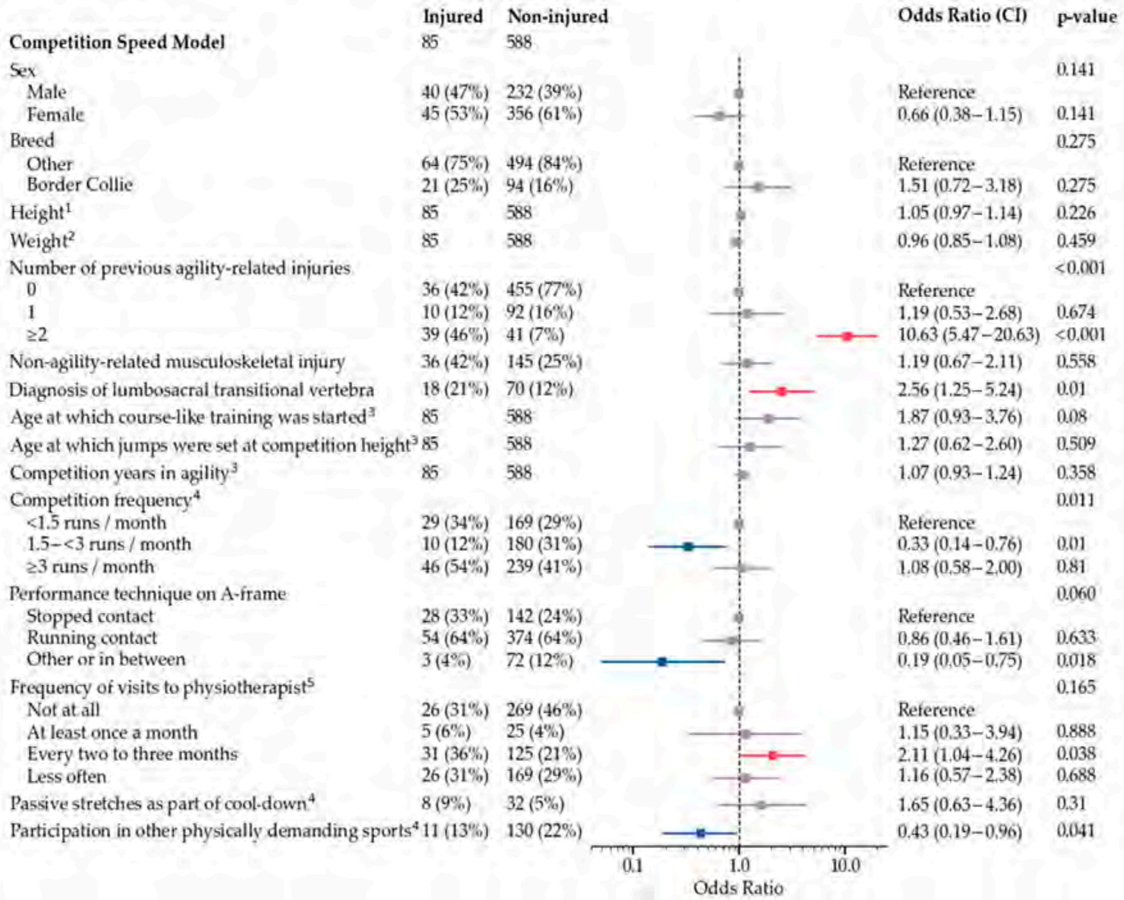

Figure 5. Competition speed model for odds of agility-related injury during 2019. [1] For a one centimeter increase, the odds increase by OR. [2] For a one kilogram increase, the odds increase by OR. [3] For a one year increase, the odds increase by OR. [4] Routines during the three-month period preceding injury in injured dogs and during 2019 in non-injured dogs. [5] Routines during the one-year period preceding injury in injured dogs and during 2019 in non-injured dogs.

4. Discussion

This study provides information on agility-related injuries of competition-level Finnish agility dogs during 2019. Over 10% of the agility dogs in our study suffered an agility-related injury, with most injuries occurring in training and presenting as lameness. The rate of competition-related injuries was 1.44 injuries/1000 competition runs. Front limbs were most prone to injuries. As hypothesized, previous agility-related injuries were a significant risk factor for agility-related injury during 2019. Information on non-agility-related musculoskeletal injuries improved the logistic regression models, but was a non-significant factor, and thus, its role remains unclear. Contrary to our hypothesis, competition speed of the dog did not contribute to the injury risk. As expected, high training frequency was associated with increased odds of injury.

4.1. Injury Rate

In our sample, almost a third of the dogs had suffered an agility-related injury during their career, which is in agreement with most previous studies [2,5]. Higher proportions of injured agility dogs, almost 50% of Scandinavian agility dogs and over 40% of agility dogs worldwide, have been reported recently [8]. However, that study included also non-agility-related injuries and orthopedic conditions, likely leading to the higher proportions than in other studies [8]. The incidence of sport- or work-related injuries appears lower in agility dogs than in greyhounds, working farm dogs, or gundogs [13–15]. In flyball dogs, injury risk appears to be similar to agility dogs [11,16]. However, the definition and recording of injuries varies across the studies, making comparisons difficult. In our sample, the rate of competition-related injuries was slightly lower than the previously reported rate of 1.72 injuries/1000 runs in North American agility dogs [3]. Course designs and regulations are likely to differ between Finland and North America, possibly leading to different injury rates. Additionally, management and training routines in Finland differ from those in the USA [3,6,7], which could affect injury rate in competitions.

Most injuries in our study occurred during training, with most training-related injuries occurring in the second half of the training session, suggesting that fatigue may be involved. Similarly, three-quarters of competition-related injuries occurred in the second or later run of the day, when anecdotally dogs complete two to three runs per event. High-impact activities should be avoided when the dog is fatigued to prevent injuries [17]. Thus, handlers and coaches should be educated in detecting signs of fatigue such as excessive panting, muscle trembling, and gait changes [18]. However, the usual length of a training session as such was not associated with increased odds of injury in our sample.

4.2. Obstacle-Related Injuries

The obstacles most commonly involved in injures, according to earlier reports, are bar jump, A-frame, and dogwalk [2,4]. Interestingly, in addition to these obstacles, injuries during performance of open tunnels were relatively common in our study, whereas previously open tunnels have only seldom been associated with injuries [2,4]. Observations from the field suggest that the speed of the dogs has increased over the years, materials of tunnels have evolved to improve the grip for the dog, and the attachments of tunnels has become more fixed—possibly increasing the hazards of open tunnels. A larger sample of tunnel-related injuries will be needed to determine which tunnel-, dog-, or course design-related factors are associated with injuries in tunnels.

Traumatic injuries resulting from normal sport activity or sport-related accident are considered rare in most canine sports [17]. However, contradictory to this assumption, collision with an obstacle was a relatively common cause of agility-related injury in our sample as well as in previous studies [2,4]. In our study, collisions were particularly common on jump obstacles compared with other obstacles, possibly because they are the most common obstacle type on the course [2]. Attention should be paid to materials of obstacles; lightweight obstacles are going to reduce the impact to the dog in the case of collision with the obstacle. Multiple potential causes, such as handling error, course planning, slippery surface, fatigue of the dog, or dog's visual impairment, may lead to a collision. Analysis of video material available from collisions might help to identify some of the most common causes.

Falls from A-frame and dogwalk have not been separated from collisions in previous studies, although both obstacles have been commonly associated with injuries [2]. In our sample, a fall was common among dogwalk-associated injuries. Equipment recommendations and rule changes have been suggested as possible aids to reduce sport-related injuries in human sports [19]. Thus, falls from the dogwalk could probably be reduced by changing the regulations for the obstacle's dimensions, with width currently being only 30 cm [20]. In addition to obstacle dimensions, an angled approach at speed may be a factor leading to falls from the narrow plank. Regulations should be updated regularly to ensure safe performance, also at the higher speeds of modern agility dogs. Such changes have already been made regarding the tire obstacle, which must break in case of collision [20], possibly decreasing the proportion of injuries associated with the tire from the previously reported 6% to below 2% in our study [4]. Similar improvements should be made for the dogwalk and the A-frame, which are commonly involved in injuries despite being performed on a course much less frequently than bar jumps [2].

All dogs with A-frame-associated injury in our sample had been trained to perform the obstacle with the running contact technique, although in the whole sample also other techniques were common. This suggests that the running contact technique may be associated with a higher risk for A-frame-related injuries. A larger sample size is required to further assess injuries related to the A-frame. When evaluating risk for agility-related injury in general, the running contact technique used at the A-frame was associated with similar odds of injury as the stopped contact technique. Dogs with other, or in between, techniques had lower odds of agility-related injury. Anecdotally, these dogs generally decelerate on the descending part of the A-frame without an abrupt stop at the end. This may decrease stress on the musculoskeletal system and reduce the risk of injuries in general.

4.3. Anatomical Location and Treatment

In our study, six out of ten dogs injured their front limbs, which is a higher proportion than previously reported in agility dogs [5]. The reason for this difference is unknown. Front limbs are, however, subjected to high demands during obstacle performances. During jumping higher peak vertical forces are applied to the front limbs than to the hind limbs; peak vertical forces are on average 2.5 times the body weight for each front limb in advanced agility dogs [21]. Excessive carpal extension, outside the reported passive range of motion values, has been described at first contact with the A-frame and when landing from a jump [22–25]. Additionally, jumping and performing A-frame requires marked activation of front limb muscles in the shoulder region [26,27]. Thus, the high proportion of front limb injuries is not surprising. To take this into account, agility dogs could benefit from coordination, proprioception and strength training targeted especially to front limbs. Future studies should evaluate the effect on professionally-planned conditioning programs on injuries in agility.

Veterinary care was sought only for 40% of the injuries in our sample, whereas in previous reports, in mainly North American populations, the proportion has been 61–78% [2,4]. The recovery times suggest that minor injuries were slightly more common in our sample [2,4], which could explain some of this difference. Lack of proper diagnosis may lead to insufficient treatment and rehabilitation in some cases, potentially resulting in re-injury.

4.4. Risk Factors

Previous agility-related injuries have been reported to significantly increase the risk of new agility-related injuries [7], a finding confirmed by our study. However, in our sample, having multiple agility-related injuries significantly increased the odds of injury, whereas having only one previous injury was not a major factor. Attention should be paid to rehabilitation and conditioning of dogs after an injury, especially in dogs with a history of multiple agility-related injuries. After injury rehabilitation, additional conditioning is required to re-gain full function to meet the demands of the sport [28]. Physiotherapist-guided rehabilitation and conditioning were used for only one-fifth of the cases in our study, suggesting that there is room for improvement. Additionally, there may be certain properties of dogs, such as conformation or personality traits, that predispose them to being repeatedly injured even after appropriate rehabilitation.

Starting age has not been evaluated as a risk factor in previous studies, but it was an important factor in our model. Starting course-like training, where dogs perform obstacle sequences including jumps, at an older age doubled the odds of agility-related injury during 2019 for each year added. Traditionally, high-intensity activities have been discouraged in dogs during their first 12–18 months before all growth plates have closed [28]. Based on anecdotal data, dogs that repeatedly perform jumps or weaves at a young age have been proposed to be at increased risk for chronic injuries later during their career [28]. Our findings were not in line with this. In contrast, our results suggested that with a median starting age of 12 months for course-like training, starting early, probably before closure of all growth plates in many dogs, was protective for agility-related injury later in their career. Similarly, racehorses starting racing or training as two-year-olds have lower risk of injury than horses starting at an older age, probably because of better adaptation capacity at a younger age [29]. However, additional analysis of our sample revealed no association between agility-related injury during the whole career (2019 or earlier) and starting age. Thus, the initial finding could be coincidental, describing only the sample used for the regression models. Additionally, young dogs just starting agility did not generally meet our inclusion criteria, as only competing dogs were included and most had started training before 2019. Thus, whether early start affects the risk of injury during the early training stages could not be evaluated in this study. More research is needed to set recommendations for the training of young dogs.

Frequency of training sessions has not been related to agility-related injury in previous studies [5,7]. However, the training frequency was asked for the past year before participation in the survey, which may not represent training frequency prior to the injury. In our study, high training frequency prior to the injury was associated with higher likelihood of agility-related injury in the training frequency model. This could have been simply due to high exposure to agility in dogs that train often. However, weekly training time was not associated with injury. Dogs with high training frequency may not have had sufficient time to recover from training before the next session. In human athletes, there is conflicting evidence on the association between training frequency and injury [30]. However, an increase in the short-term amount of training in relation to the long-term amount increases the risk for injury (acute: chronic workload ratio) [30,31]. In our sample, the high training frequency prior to injury may indicate a peak in training frequency, possibly with an abrupt increase in training load in some dogs. However, we only asked about the usual training frequency during the preceding three months, not allowing for a detailed evaluation of the variation in training over the weeks. A prospective study design with repeated surveys or objective activity measurements is recommended to track training load in detail.

Competition frequency, like training frequency, has not been associated with agility-related injuries previously, but the earlier surveys did not include questions that recorded routines prior to injury [5,7]. In our study, a moderate frequency of competition runs was associated with lower odds of agility-related injury compared with dogs competing at low or high frequency. Dogs competing at a low frequency, on average less than 1.5 runs a month, may be insufficiently prepared for the demands of the sport compared with dogs competing more often, and competition runs may represent an abrupt increase in high-intensity activity for these dogs. A high average number of monthly competition runs is the result of a higher frequency of competition days, a higher number of runs per competition day, or both. As injuries often occurred during the second or later runs, a high number of daily runs might increase the risk of competition-related injury.

The presence of a lumbosacral transitional vertebra (LTV) was another major risk factor in all of our models. To our knowledge, this unexpected finding has not been reported previously. The LTV has been described to be associated with cauda equina syndrome [32]. However, in that study there were no dogs that had a separation of the first spinous process from the median crest of the sacrum (LTV1) [32], which was the most common type in our sample. Anecdotally, LTV1 is considered to be a mild abnormality, not necessarily of any clinical relevance. In dogs with LTV, including dogs with LTV1, the length of the L7 in relation to the L6 is increased compared with dogs without LTV [33]. The kinematics of the back may be affected in clinically sound dogs with radiographic changes in the lumbosacral junction; however, only a couple of dogs in that study had LTV and the grade was not specified [34]. Thus, the information on clinical and biomechanical effects of LTV, especially in dogs with a separation of the first spinous process from the median crest of the sacrum, is sparse and further research is needed. Agility could provoke clinical signs associated with abnormalities in the lumbosacral region, especially in dogs jumping higher fences, which results in greater extension of the lumbar spine [26]. Additionally, if the function of the hind limbs or back is compromised by the LTV or associated abnormalities, it could affect risk of injury of other tissues. Alternatively, owners and handlers of dogs with known LTV may observe their dogs more carefully or be more likely to rest their dog in case of minor signs.

Our study showed that participation in other physically demanding sports may protect from agility-related injury, a finding that has not been reported previously. These other sports may provide conditioning that prepares the dogs for the physical demands of agility. Similarly, human athletes highly specialized in one sport have greater risk of overuse injury than athletes with less specialization [35,36]. In humans, this effect may be independent of amount of training [35]. Low diversity in the movement patterns practiced by specialized athletes may affect the development of neuromuscular skills that protect from injury [37]. Additionally, certain parts of the body may get insufficient rest from repetitive activities [37]. Variation in physical exercise may thus be advisable also for agility dogs.

To our surprise, competition speed was not associated with injury, suggesting that other factors had greater effect on the odds of injury. Alternatively, the method of evaluating dogs' speed may be inaccurate; competition speed is calculated in the competition results database from course time of a faultless run divided by course length measured by the judge. However, the expected route measured by the judge may differ from the actual route of the dog over the course. The course time is also affected by the handler's ability to train obstacle skills and to guide the dog on the course. Courses differ in the number and tightness of turns as well as in obstacles, and difficulty increases with level. Thus, the competition speed value may not reliably represent a dog's running speed in agility.

Musculoskeletal care has been associated with agility-related injury in previous studies, but the timing of the therapies in relation to injury was not evaluated in these studies so they could also be a result of reversed causality [3,7]. In our sample, dogs receiving physiotherapy every two to three months during the year preceding injury had increased odds of injury, even when controlled for previous injuries. Thus, physiotherapy appears to be associated with injury independently from previous injuries. Possibly owners choosing to provide regular physiotherapy for their dog are more likely to notice their dog's clinical signs and/or to restrict training or exercise in case of even minor signs. The owners may also have been taught observation or palpation skills by the physiotherapist, which allowed them to recognize minor abnormalities. It is unlikely that the finding would be explained by injuries detected during physiotherapy, as in our study clinical signs had to be evident within 24 h of agility and dogs with higher odds of agility-related injury visited the physiotherapist every two to three months. It cannot be ruled out that some practices or recommendations from the physiotherapist might have increased the risk of injury.

4.5. Study Design and Limitations

To our knowledge, a definition of injury per se has not been provided to respondents in previous questionnaire studies [2,4,5]. The time-loss definition, defining injury as a physical complaint resulting from the sport and leading to time lost from training and competition, is used in human sports [38,39] and was chosen for our study. Because dogs do not complain about discomfort, clinical signs observed by the owner were used instead. The owner also evaluated whether the clinical signs were caused by agility. As many agility dogs can have multiple days in between agility sessions, time lost from usual physical exercise was additionally included in our definition. This allowed for minor injuries, leading to exercise being restricted for only one or two days, to be included in this study.

A relatively high number of dogs that were reported as injured had to be excluded from this study, mainly because clinical signs were not observed within 24 h of training or competing in agility. Perhaps, the criteria outlined in the initial question of agility-related injury was not understood correctly or not read thoroughly. In some cases, clinical signs, such as pain on palpation, were detected by a physiotherapist or other professional only at a later time. Thus, it may be that these signs went initially unnoticed by the owner or the handler. However, once the time between the agility session and the clinical signs increases, it becomes more likely that the clinical signs are unrelated to agility. The 24-h criterion was chosen since we expected that in most cases clinical signs develop within this time frame. It appears that respondents may intuitively define agility-related injury in different ways. We recommend that in future questionnaire studies the injury should be defined clearly to respondents with own check boxes for each criterion used.

Most of the previous survey studies on agility-related injuries have requested details of injuries during the whole career or at least over a two-year period before participation [2,4,5]. We covered in detail injuries occurring only over one year, which is likely to have improved respondents' ability to accurately remember passed events. Despite this, for many dogs, anatomical location and type of injury were subject to being imprecise and clarifications were sought through email. In some cases, the veterinary diagnosis described in open field was not in agreement with the checked boxes for anatomical location and/or type of the injury, highlighting the issue. Many dogs did not receive veterinary care and the location and type of injury relied on the evaluation of the owner or paraprofessional. Additionally, selection bias could have affected our results; for example, injured dogs could have been overrepresented if their owner perceived the study as more important and were therefore more likely to invest time in participation than owners of non-injured dogs. The latest injury from 2019 was included in the analyses if there were multiple injuries for one dog, as several injuries could not have been analyzed independently of each other. Additionally, the respondents are likely to remember the latest injury most accurately, improving the quality of the data. This selection criterion could have resulted in a majority of injuries being from the end of the year, possibly associated with certain conditions. However, most dogs had just one injury.

Factors included in each model were mainly the same, especially the most significant ones. To select variables for development of the multivariate models, variables with $p < 0.1$ in univariate analysis were chosen. With this threshold, a high proportion of dogs had no missing values in most of the variables chosen for the development of multivariate models. With a higher threshold, such as $p < 0.2$ or <0.25 used in some previous studies [5,7], a greater number of variables would have been chosen for the model development and therefore a greater proportion of dogs would have had missing values in at least one of the variables. This would have resulted in a markedly smaller population to be used for multivariate model development. To include as many dogs as possible in the final model, we chose to exclude some variables from it and analyzed them separately in the subgroup analyses. With a larger sample, which could be achieved by an international sample, all variables could have been included in the same model. However, an international population would not allow utilizing objective data from national competition result databases. Additionally, translating the questionnaire would be required to get sufficient samples also outside countries with English as the native language, which brings issues with possibly different meaning of questions in different languages. One should also remember that these models detect only associations, not causality. Some risk factors may also be linked to some other factors, not covered by the questionnaire.

5. Conclusions

Agility dogs are prone to soft tissue injuries to their front limbs, with most injuries occurring during obstacle performances. Dogs with multiple previous agility-related injuries, lumbosacral transitional vertebra, later starting age in the sport, and high training frequency appear to be at greatest risk for agility-related injury. Multiple additional, less significant factors improved our models in predicting odds of agility-related injury in our sample. Reviewing obstacle regulations could aid in reducing some obstacle-related injuries.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ani12030227/s1, File S1: Link to the final questionnaire, Table S1: Breeds of dogs with agility-related injury during 2019, Table S2: Variables associated with increased or decreased odds of agility-related injury during 2019 in univariate logistic regression analysis. Video S1: Demonstration of agility obstacles.

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Informed Consent Statement: In the opening text of the survey, respondents were informed about the content and purpose of the study and about management of personal data. Participation was voluntary. All respondents gave their informed consent when participating in the online survey.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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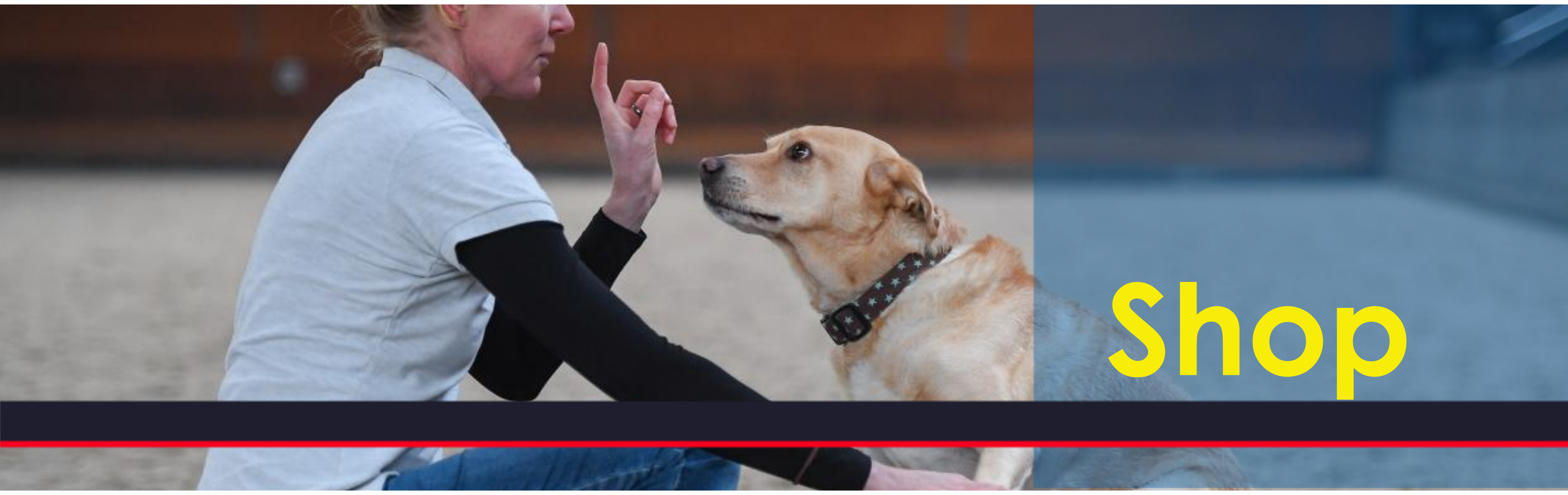

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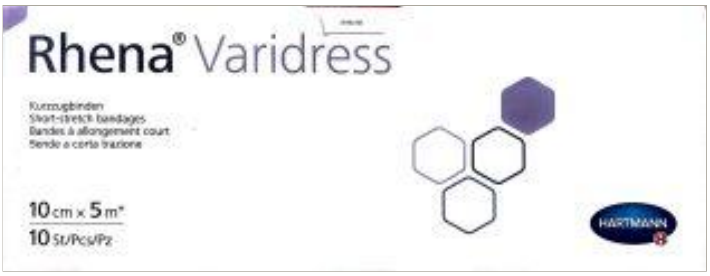

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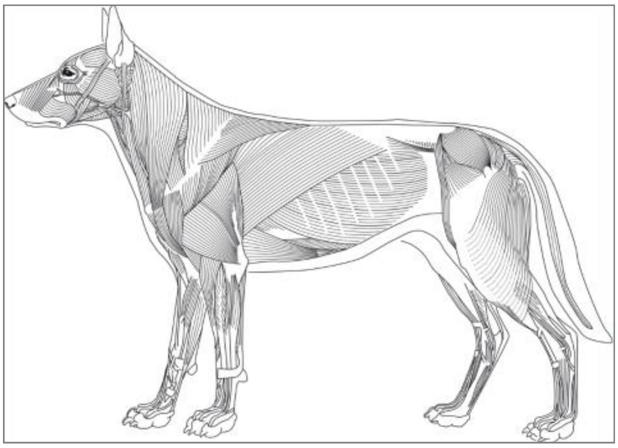

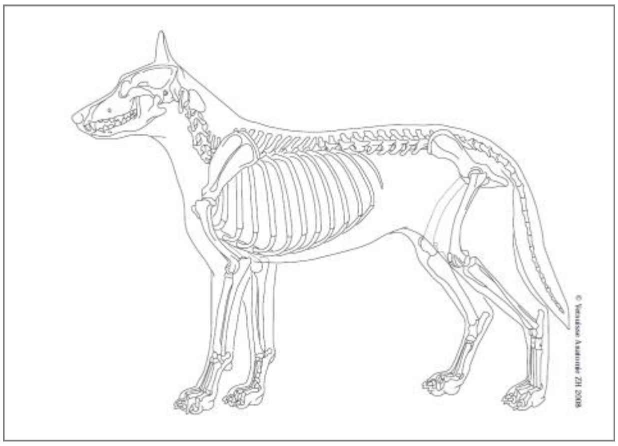

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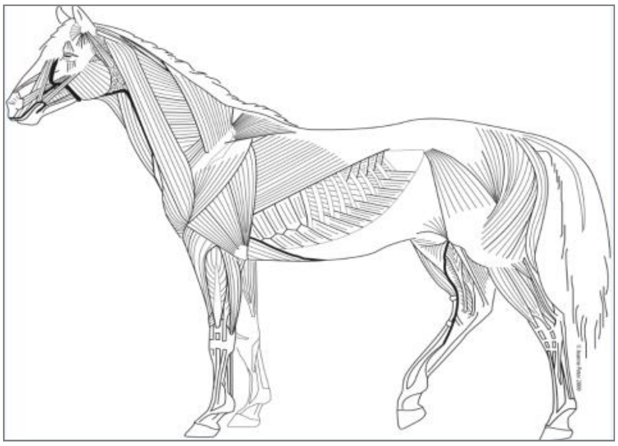

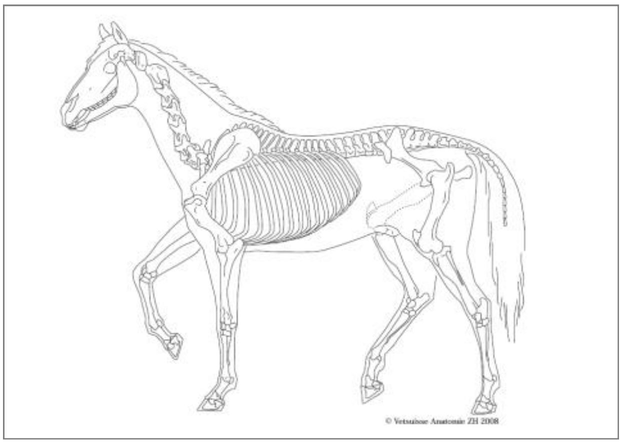

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