

REVIEW

Horseshoe effects on equine gait—A systematic scoping review

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Abstract

Objective: To provide an overview of available research about effects of horseshoes on equine kinetics and kinematics.

Methods: The terms, “horse/equine,” “hoof,” “shoes/horseshoes,” “kinetics,” and “kinematics” were searched in PubMed, Web of Science, Center for Agriculture and Bioscience International, and United States Department of Agriculture National Agricultural Library for manuscripts from first availability to 2024. Independent reviewers used preferred reporting items for systematic reviews and meta-analyses guidelines to map and extract evidence-based data from sources. Metrics included participant demographics, research methods, major findings, and study limitations. Knowledge gaps were also identified.

Results: A total of 46 studies were included. Most utilized non-lame horses to compare original shoe designs or modifications to unshod or a standard open-heel shoe. Horse demographics and gait, study design and outcome measures varied widely. Prevalent data collection equipment included force platforms and pressure plates, wearable force measuring technology, and videography. Many studies reported shoeing effects on limb forces and motion, but there was little consensus among unrelated studies. Common limitations included insufficient data resolution, no randomization, small sample size, single breed, and outcome measures specific or unique to the study. Knowledge gaps included data collection from all limbs and the impact of conformation and limb and hoof morphology and health condition on outcomes.

Conclusion: Information from manuscripts that met inclusion criteria confirmed distinct, variable effects of shoe characteristics on equine gait parameters.

Clinical significance: Details from published work can serve as resource for clinical decisions and to guide standardization among investigations on shoe configuration effects on equine motion.

Abbreviations: 2D, Two-dimensional; 3D, Three-dimensional; CABI, Center for Agriculture and Bioscience International; SD, Standard deviation; USDA, United States Department of Agriculture.

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1 | INTRODUCTION

Horses are ungulates, bearing their weight on the distal phalanx surrounded by a cornified hoof wall that can be worn away by abrasive surfaces during motion. Horseshoes, usually composed of metal, have long been used to reduce hoof wear and protect the solar hoof surface and heels.^{1,2} Modern farriery includes horseshoe designs and materials customized for specific purposes. Shoe length, width, weight, and height can be modified to correct conformation, support injured tissue, and alter gait characteristics.^{1–5} Kinetic and kinematic evaluations are used to confirm the specific effects of shoe composition and configuration on the gait.

Interactive forces and energy of motion are quantified as part of kinetic assessments. Force platforms are standard to record the direction and magnitude of ground reaction forces along three axes, vertical, horizontal (craniocaudal), and transverse (mediolateral). From raw data, standardized metrics like peak force and impulse, as well as stance, braking and propulsion times can be quantified for evaluation and comparison.⁶ Limb motion is measured with kinematic analyses and can include metrics like limb segment velocity, acceleration, and angulation. Combining kinetic and kinematic measures makes it possible to evaluate the relationship between forces and motion. Methods from both kinetics and kinematics are applied separately and together to quantify shoe effects on equine gait.^{7–9} The information is vital to inform decisions about the use of distinct shoe designs based on their intended purpose and effects on locomotion.

A lot of published information surrounding horseshoe effects on equine motion is anecdotal. There are challenges inherent to quantifiable data collection like access to equipment and technology and resources to reduce and analyze resulting data. However, there are sustained efforts to improve equine treatment, performance, and safety by assessing horseshoe kinetic and kinematic impacts. Kinetic and kinematic studies in horses are relatively less common compared to other species, and approaches vary widely among them. As such, available, quantifiable data has not yet reached sufficient levels for a systematic meta-analysis. However, a qualitative scoping review focused on contemporary methodology and technology is important to establish consistent standards among investigations and identify knowledge gaps for future investigative focus.^{10–14}

The aims of this systematic scoping review were to summarize published technology and methods to evaluate effects of horseshoes on equine kinetics and kinematics, highlight major findings of recent research, and identify areas for future study. The research questions were (1) What methods, technologies, and outcomes are used to assess kinetic and kinematic effects of equine

shoeing? (2) What are the existing knowledge gaps surrounding shoe effects on equine kinetics and kinematics? Information collected from each study included subject demographics, shoe configurations, data collection and analysis methods, major findings, and limitations. The results of this work highlight contemporary assessment mechanisms and establish a foundation on which to base methods, standards, and aims for future investigations.

2 | MATERIALS AND METHODS

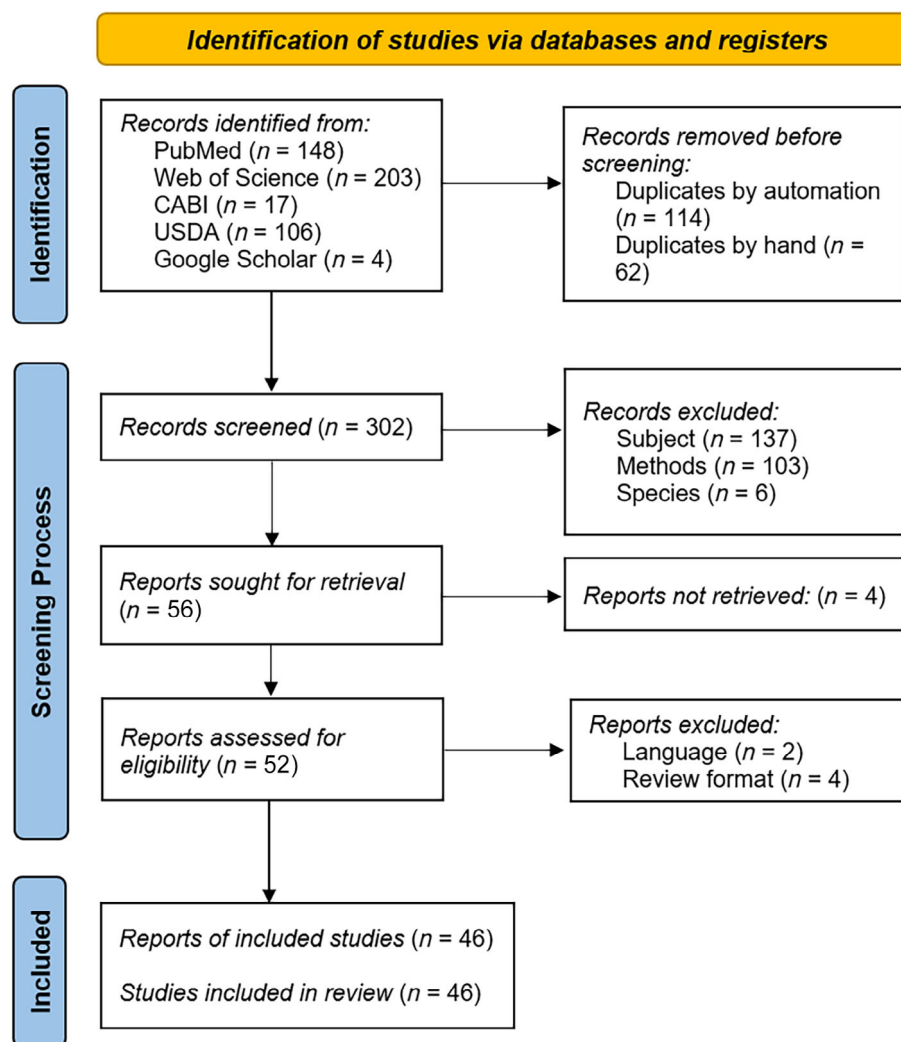
2.1 | Databases and search strategy

The search strategy for the current study was based on the Population Intervention Comparison Outcome rubric. The search terms “equine,” “kinetics,” “gait,” “kinematics,” “shoe,” “braking,” “propulsion,” and “force” were used individually and combined with the conjunctions: “OR” and “AND.” Databases searched were PubMed, Web of Science, Center for Agriculture and Bioscience International (CABI), and United States Department of Agriculture (USDA) National Agricultural Library from the earliest available date to April 2024. The search string used for all databases was: (horse OR equine) AND (gait OR locomotion OR mechanic* OR kinetic* OR kinematic*) AND (ground reaction force OR force OR peak force OR impulse OR load* OR pressure OR joint OR joint angle OR displacement OR braking OR deceleration OR propulsion OR acceleration OR impact OR breakover OR slip) AND (shoe* OR horseshoe* OR farrier* OR coaptation OR boot OR clog). Asterisks were added to some key terms, the root word followed by the truncation symbol, to instruct databases and search engines to search for plurals or other word forms. Additionally, a manual search was performed in Google Scholar to retrieve sources that were not automatically found using the above search strategy.

2.2 | Source selection criteria

Duplicate manuscripts from different search engines were removed from those retrieved with the search terms above. Two independent investigators reviewed all manuscripts for population, concept, and context criteria that were established a priori based on the Joanna Briggs Institute manual for reviews.¹⁰ Initially, titles and abstracts were reviewed to determine eligibility, and then full manuscripts were evaluated for inclusion criteria. In cases of dissensus, manuscripts in question were reviewed by a third reviewer, and eligibility determined by the majority. Individual sources were not critically reviewed for risk of bias consistent with scoping review guidelines.¹⁵

FIGURE 1 Preferred Reporting Items of Systematic Reviews and Meta-analyses (PRISMA) schematic illustrating the literature search and screening processes.



In addition to content composed of equine kinetic and/or kinematic gait assessment in vivo, manuscript inclusion criteria were publication in a peer-reviewed journal, available in the English language, and full text accessible through open access, institutional subscription, or interlibrary loan. Reasons for exclusion were investigative focus or methods outside the target area, cadaveric investigations, non-equine species, and review article format.

2.3 | Data extraction and thematic analysis and synthesis

Specific data extracted from each source included authors, publication year, participant demographics (age, weight, breed, and lameness), methods (test and control shoes, gait, technology employed, and outcome measures), major findings, and limitations. Since limitations were not included in all manuscripts, they were categorized as author-acknowledged limitations, limitations included in the manuscript text, or reviewer-identified

limitations, limitations identified during evaluation of the source for this scoping review. A standard approach was employed to map available information, and evidence-based data extracted from selected sources, including study limitations described above, was categorized and assimilated into tables and figures. Results were then synthesized to systematically detect and present available evidence-based information about studying the effects of shoe configuration on equine kinetics and kinematics.

3 | RESULTS

3.1 | Screening process and study selection

The database search yielded a total of 478 imported manuscripts via PubMed ($n = 148$), Web of Science ($n = 203$), CABI ($n = 17$), and USDA ($n = 106$), and four citations imported via a manual search in Google Scholar ($n = 4$) (Figure 1). After removing duplicates by automated

TABLE 1 Study sample size, horse age, weight, breed, and lameness.

Study	Sample size	Age (years, range or mean $\pm$ SD)	Weight (kg, range or mean $\pm$ SD)	Breed	Lameness
Al Naem et al. (2020) ⁴⁶	8	8–22	330–550	Icelandic horse, Welsh pony, Warmblood, Arabian, Quarter Horse	Acute laminitis
Amitrano et al. (2016) ⁹	6	0.92–1.2	340–375	Standardbred	Sound
Barrey (1990) ¹⁶	20	5–25	452–594	Selle Francais, Trotteur Francais, Anglo-Arab, Camarguais	Sound
Caure et al. (2018) ⁴⁸	6	8–19	430–720	Trotter, Lipizzaner, French saddle pony	Sound
Chateau et al. (2004) ²²	4	-	-	French trotter	Sound
Chateau et al. (2006) ²³	4	-	-	French trotter	Sound
Clayton et al. (1991) ²⁴	8	-	-	Thoroughbred and Thoroughbred-cross	Sound
Clayton et al. (2000) ²⁵	6	-	-	Warmblood	Mild, consistent lameness from induced superficial digital flexor tendinitis in one forelimb
Day et al. (2020) ²⁶	10	-	-	-	Sound
Duberstein et al. (2013) ³⁶	8	3–21	-	-	Sound
Eliashar et al. (2002) ²⁷	9	-	539–660	Irish draught-cross	Sound
Hagen et al. (2016) ³⁷	25	8.9–9.1	-	Warmblood-cross	Sound
Hagen et al. (2017) ³⁸	25	8.8–9.8	-	Warmblood-cross	Sound
Hagen et al. (2021) ³⁹	10	10.7 $\pm$ 2.79	-	Dutch Warmblood, Friesian, Tinker horse, riding pony	Sound
Hagen et al. (2023) ⁴⁰	10	10.7 $\pm$ 2.79	-	Dutch Warmblood, Friesian, Irish cob, riding pony	Sound
Harvey et al. (2012) ⁴⁴	9	5–14	522.4 $\pm$ 46.8	-	Sound
Horan et al. (2021) ⁴⁹	13	6–20	421–555	Thoroughbred	Sound
Huguet et al. (2012) ⁴¹	9	4–21	-	Quarter Horse, Quarter Horse-draft cross, Appaloosa, Quarter Horse-Arabian cross	Sound
Hüppler et al. (2016) ⁴²	25	8.8–9.8	-	Warmblood-Crossbred	Sound
Kai et al. (2000) ⁵⁰	5	4–7	452 $\pm$ 17.1	Thoroughbred	Sound
Keegan et al. (1998) ²⁸	5	-	-	Quarter horse	Navicular disease
Kicker et al. (2004) ⁴⁵	26	11 $\pm$ 6	533 $\pm$ 53	Warmblood	-
Panagiotopoulou et al. (2016) ²⁹	1	-	540	Thoroughbred	Sound
Panos et al. (2023) ³⁰	14	-	-	Morgan, Thoroughbred, Friesian Morgan, Andalusian	Mild lameness

TABLE 1 (Continued)

Study	Sample size	Age (years, range or mean $\pm$ SD)	Weight (kg, range or mean $\pm$ SD)	Breed	Lameness
Pardoe et al. (2001) ³¹	8	-	-	-	Sound
Paz et al. (2019) ⁴⁷	12	(a) 8.3 $\pm$ 4.7; (b) 10.2 $\pm$ 3.85	(a) 381 $\pm$ 26; (b) 381 $\pm$ 11	Mangalarga Marchador	(a) Sound; (b) Laminitic
Peham et al. (2006) ³²	8	-	-	Warmblood	Sound
Reilly (2010) ⁴³	2	(a) 16; (b) 4	-	(a) Quarter horse, (b) Dutch Warmblood	-
Riemersma et al. (1996) ¹⁸	5	2–13	165–240	Pony	Sound
Roepstorff et al. (1999) ⁷	6	4–12	489–652	Swedish Warmblood	Sound
Rogers et al. (2007) ³³	6	-	518–588	Warmblood	Sound
Rumpler et al. (2010) ⁵¹	8	12 $\pm$ 3	369 $\pm$ 46	Icelandic horse	Sound
Scheffer et al. (2001) ⁸	11	5–14	504–616	Dutch Warmblood	Sound
Singleton et al. (2003) ³⁴	6	-	477–627	-	Sound
Sleutjens et al. (2018) ¹⁹	10	(a) 4 $\pm$ 1.5; (b) 5 $\pm$ 1.8	(a) 185 $\pm$ 19; (b) 244 $\pm$ 36	Shetland pony	Sound (a) normal; (b) obese
Spaak et al. (2013) ⁵²	10	7.8 $\pm$ 2.7	515 $\pm$ 46	Warmblood	Sound
Stutz et al. (2018) ⁵³	10	11.8 $\pm$ 4.9	534.5 $\pm$ 31.3	Franches-Montagne	Sound
Thompson et al. (1994) ³⁵	6	-	420–525	Thoroughbred	Sound
Van Heel et al. (2005) ⁵⁴	18	4.9 $\pm$ 2.3	569.4 $\pm$ 40.7	Warmblood	Sound
Van Heel et al. (2006a) ⁵⁵	20	6.2 $\pm$ 2.6	581 $\pm$ 55.0	Warmblood	Sound
Van Heel et al. (2006b) ⁵⁶	18	4.9 $\pm$ 2.3	569.4 $\pm$ 40.7	Warmblood	Sound
Waldern et al. (2013) ⁵⁷	13	10 $\pm$ 3	356 $\pm$ 24	Icelandic horse	Sound
Wang et al. (2021) ¹⁷	5	10–25	400–600	Quarter Horse, Tennessee walker	Sound
Weishaupt et al. (2013) ⁵⁸	13	10.1 $\pm$ 3.3	356 $\pm$ 24	Icelandic horse	Sound
Willemen et al. (1996) ²⁰	12	2.5	470–590	Dutch Warmblood	Sound
Willemen et al. (1997) ²¹	12	2.5	470–590	Dutch Warmblood	Sound

Abbreviation: SD, standard deviation.

($n = 114$) or manual ($n = 62$) review, additional studies were removed based on identification of exclusion criteria in the title, abstract, or full text ($n = 250$). Subsequently, studies that could not be accessed ($n = 4$) or were not available in the English language ($n = 2$) were removed. At the conclusion of the screening process, a total of 46 manuscripts qualified for thematic analysis.

3.2 | Demographic characteristics

The number of horses included in the recognized studies ranged from four to 26 with an average sample size of 11 horses (10.98 $\pm$ 0.9, mean $\pm$ SEM). Among reports that included horse age and weight, the parameters varied widely, 11 months⁹ to 25 years,^{16,17} 165–280 kg for ponies,^{18,19} and 330–720 kg for horses (Table 1). Most studies included horses

≥ 4 years, with exceptions of 11–12 months⁹ and about 2.5 years.^{20,21} Some studies did not report horse age ($n = 14$)^{22–35} and/or weight ($n = 16$).^{22–26,28,30–32,36–43} Altogether, 28 distinct breeds were reported; the Warmblood (23.9%), Warmblood-cross (17.4%), Thoroughbred (13%), and Quarter Horse (10.9%) had the highest representation. A total of five reports did not include the breeds.^{26,31,34,36,44} Most studies reported results of lameness evaluations with two exceptions.^{43,45} Five (10.9%) of the reports included horses with lameness^{25,28,30,46,47} while 84.8% ($n = 39$) included only sound (non-lame) horses.

3.3 | Shoe characteristics

The standard flat shoe (also known as normal or open-heal shoe) with or without modifications was most highly

TABLE 2 Study test and control shoe configurations.

Study	Shoe treatment	Control
Al Naem et al. (2020) ⁴⁶	Hoof cast with heel wedge	Unshod
Amitrano et al. (2016) ⁹	Hoof boot with silicone padded wedged bottom; steel toe extension shoe	Unshod
Barrey (1990) ¹⁶	Open-heel shoe with four force transducers integrated into the bottom of a horseboot	-
Caure et al. (2018) ⁴⁸	Front with aluminum open-heel shoe and hind with egg bar, reverse, or covered toe shoe; front unshod and hind with steel race shoe; front with aluminum shoe and hind unshod; all four unshod	Front with aluminum open-heel shoe and hind with open-heel steel race shoe
Chateau et al. (2004) ²²	Custom combined support and removable shoe, 6° heel wedge	Custom combined support and removable standard shoe
Chateau et al. (2006) ²³	Custom combined support and removable shoe with egg-bar shoe	Custom combined support and removable shoe with standard shoe
Clayton et al. (1991) ²⁴	Plain steel shoe; rocker-toe shoe; rolled-toe shoe; square-toe shoe on one limb	Plain steel shoe on one limb
Clayton et al. (2000) ²⁵	Flat shoe with 6° heel wedge flat shoe with or without 5-day adaptation	Flat shoe
Day et al. (2020) ²⁶	Shoes with a tungsten carbide road nail in the last nail hole of the lateral heel	Shoes without tungsten carbide road nails
Duberstein et al. (2013) ³⁶	Glued-on aluminum plate shoe with an aluminum heel plate and toe plates placed flush with the toe, and 0.5, 1, or 1.5 inches caudal to the toe	-
Eliashar et al. (2002) ²⁷	Wide-web toe clip; quarter clip; Natural Balance shoes	-
Hagen et al. (2016) ^{37,a}	(a) Wide branch shoe; (b) unilateral roller shoe; (c) side wedge open-heel shoe	Unshod, standard open-heel shoe with (a) rolled toe, toe clip; (b) rolled toe, two side clips; (c) 45° rolled toe, toe clip
Hagen et al. (2017) ^{38,a}	(a) 6° heel wedges and egg-bar shoe; (b) studs and side wedge shoe; (c) rocker shoe and heart-bar shoe	Unshod, standard open-heel shoe with (a) straight toe, (b) rolled toe, toe clip, (c) rolled toe, reset shoe, two side clips
Hagen et al. (2021) ³⁹	5° heel wedge alone; toe-clip steel shoe; toe-clip rolled-toe shoe; palmarly placed quarter-clip shoe	Unshod
Hagen et al. (2023) ⁴⁰	Lateral 120 g weight; medial 5° wedge; plain steel toe-clip; plain steel toe-clip, rolled toe-clip; palmarly placed quarter-clip steel shoe with a rolled toe; egg-bar shoe with a palmar extension; egg-bar shoe with a lateral extension; palmarly placed quarter-clip aluminum shoe	Unshod
Harvey et al. (2012) ⁴⁴	Steel shoe with lateral heel studs, 12 mm depth fore-, 23 mm depth hind	Steel shoe
Horan et al. (2021) ⁴⁹	Aluminum race plate; steel open-heel shoe; aluminum-rubber composite open-heel glue-on shoe	Unshod
Huguet et al. (2012) ⁴¹	Aluminum shoe	Steel shoe
Hüppler et al. (2016) ^{42,a}	(a) Egg-bar; (b) wide toe; (c) open-toe; (d) heart bar shoe	Unshod, standard open-heel shoe with (a) straight toe; (b) rolled toe, toe clip; (c) rolled toe, two side clips; (d) rolled toe reset shoe, two side clips

TABLE 2 (Continued)

Study	Shoe treatment	Control
Kai et al. (2000) ⁵⁰	Custom recording instrument between the hoof and a glue-on shoe	-
Keegan et al. (1998) ²⁸	Wide webbed, flat bar stock, with the toes slightly rolled. Horses with underrun heels were shod with caudally extending branches or egg-bar shoes.	Unshod
Kicker et al. (2004) ⁴⁵	Three support boots and one protective boot	No boot
Panagiotopoulou et al. (2016) ²⁹	Stainless steel shoe with toe clips	Unshod
Panos et al. (2023) ³⁰	Fullered shoe; plain stamp shoe	Unshod
Pardoe et al. (2001) ³¹	Steel shoe; plastic shoe; rubber shoe	-
Paz et al. (2019) ⁴⁷	Wooden and ethylene-vinyl acetate combined shoe; wooden, leather and ethylene-vinyl acetate combined shoe	Unshod
Peham et al. (2006) ³²	8° heel wedge; 16° heel wedges	Unshod
Reilly (2010) ⁴³	Aluminum glue on open heel shoe with removable, adjustable urethane heel wedges; aluminum egg-bar glue on shoe	-
Riemersma et al. (1996) ¹⁸	Normal flat shoe; egg-bar shoe; 7° heel wedge; 7° toe wedge	-
Roepstorff et al. (1999) ⁷	Standard iron shoe	Unshod
Rogers et al. (2007) ³³	Egg-bar; 6° wedge flat shoe	Standard shoe
Rumpler et al. (2010) ⁵¹	170 g weight boots; 280 g weight boots	No boot
Scheffer et al. (2001) ⁸	Normal shoe; egg-bar shoe; 5°-plastic heel wedge	-
Singleton et al. (2003) ³⁴	Flat shoe; egg-bar shoe	Unshod
Sleutjens et al. (2018) ¹⁹	Moldable, thermoplastic, glue-on frog-supportive shoe	Unshod
Spaak et al. (2013) ⁵²	Side-clipped shoe, set back; side clipped, rolled toe shoe, set back	Toe clipped
Stutz et al. (2018) ⁵³	Standard flat open-heel shoe; rockered-toe open heel shoe; egg-bar shoe	Unshod
Thompson et al. (1994) ³⁵	Open-heel shoe with four caulks	Standard open-heel shoe without caulks
Van Heel et al. (2005) ⁵⁴	Standard flat open-heel shoe, toe clip	-
Van Heel et al. (2006a) ⁵⁵	Standard flat open-heel shoe, toe clip, rolled toe	Standard flat open-heel shoe, toe clip
Van Heel et al. (2006b) ⁵⁶	Forelimb, standard flat open-heel shoe, toe clip and hindlimb, standard flat open-heel shoe, side clips	-
Waldern et al. (2013) ⁵⁷	Long, high front hooves shod with 3/4 fullered steel shoe with 5 mm plastic pads and silicone packing material	Trimmed hooves shod with steel shoe
Wang et al. (2021) ¹⁷	Standard shoe; standard shoe with high profile-low surface area calks; standard shoe with low profile-high surface area calks; standard shoe with thin layer of tungsten carbide; plastic-steel composite shoe	Unshod
Weishaupt et al. (2013) ⁵⁸	Long, high front hooves shod with 3/4 fullered steel shoe with 5 mm plastic pads and silicone packing material	Trimmed hooves shod with steel shoe
Willemen et al. (1996) ²⁰	Rocker-toed shoe	Standard flat shoe
Willemen et al. (1997) ²¹	Normal 10-mm thick shoe	Unshod

^aLetters in front of each control shoe in the control column correspond to a specific treatment shoe with the same preceding letter in the treatment column.

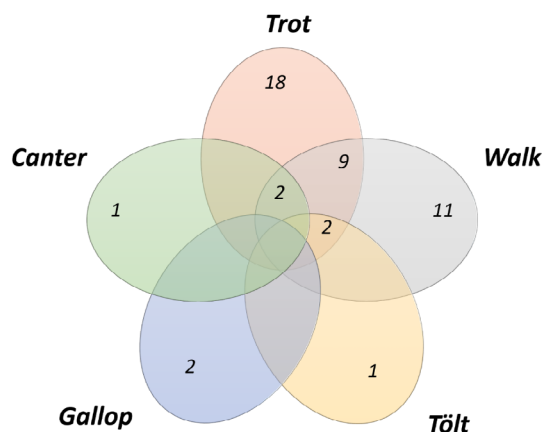


FIGURE 2 Five-way Venn diagram showing the number of studies that collected data at the indicated gaits including trot (orange), walk (gray), tölt (yellow), gallop (blue), and canter (green). Some included several gaits as shown by numbers within intersecting regions.

reported (Table 2). Egg-bar shoes were frequently included as test shoes.^{8,18,23,28,33,34,38,40,42,43,48,53} Most studies focused on evaluation of shoe shape and surface modifications, though some examined distinct shoe compositions.^{17,31,58} Unique shoe designs were often compared to unshod hooves (47.8%),^{7,9,17,19,21,28–30,32,34,37–40,42,45–47,49,51,53} or to a standard, flat, open-heel shoe with or without toe clips (23.9%)^{22,23,38,48}; some did not include a control treatment (21.7%).^{8,16,18,27,31,36,43,50,54,56}

3.4 | Data collection procedure

Gait data were most commonly recorded with horses at a trot (39.1%),^{7,17,20,21,24–28,30,31,34,41,52–56} followed by a walk (23.9%),^{9,18,22,23,29,33,37,38,42,46,47} and then equally at a gallop (2.2%),⁴⁹ canter (2.2%),⁴⁴ or tölt (2.2%)⁵¹ (Figure 2). Multiple gaits were relatively infrequently used, including walk and trot (19.6%),^{8,16,19,32,36,39,40,45,48} walk, trot, and canter (4.3%),^{35,50} or walk, tölt, and trot (4.3%).^{57,58}

Kinematic (45.7%),^{8,22–24,26,28,30,32,34–36,39–41,44,45,47–49,51,53} kinetic (28.3%),^{9,16–19,33,37,38,42,43,46,52,54} or combined kinetic and kinematic data (26.1%) were recorded (Table 3).^{7,20,21,25,27,29,31,50,55–58} Kinetic data were frequently recorded with a force platform (21.7%),^{7,9,17,18,20,21,25,27,29,31} a pressure mat or integrated pressure/force measuring system (21.7%),^{19,33,37,38,42,46,52,54–56} or, less frequently, with a treadmill equipped with a force measuring system (4.3%),^{57,58} or an instrumented shoe (4.3%).^{16,43} Two- or three-dimensional videography or optoelectronic motion recording systems (54.3%)^{7,8,20,21,24,25,27–32,34–36,41,44,45,47,48,51,55–58} were regularly used to record horse motion, and inertial measurement units were occasionally combined with other data recording systems (13%).^{26,30,39,40,49,53} In some studies (15.22%)

horses had riders during data collection.^{7,43,44,49,51,57,58} The highest focus was forelimbs or forehooves (67.4%),^{8,9,16,18–25,27–29,31,33–38,40,42,43,45–47,50,51,53,55} followed by both fore- and hindlimbs or hooves (21.7%),^{7,17,26,39,44,48,54,56–58} and least on hindlimbs alone (6.5%).^{30,32,52} Common kinetic outcome measures were ground reaction forces and impulses and center of force/pressure.^{7,9,16–21,25,27,29,31,33,46,50,52,54,55,57} Kinematic measures like joint angles, ranges of motion, and moments^{8,22–24,26,28,30,32,34–36,39–41,44,45,47–49,51,53} were frequently reported as well as temporal kinetic and kinematic measures like swing and stance duration, breakover duration, and velocity.^{9,16,17,21,23–25,27,28,33,35,39,44,46–48,50,52–54,56,57} Notably, outcome measures were often distinctly defined among different studies.

3.5 | Main results of the individual sources of evidence

Study results varied widely, and there was little consensus among studies with different populations, focus, and data recording equipment (Table 4). Shoe effects on gait kinetics and kinematics were wide-ranging and dependent on shoe treatment, gait, and reported outcome measures. Breakover parameters were affected by the heel elevation, rolled-toe shoes, and high hooves with long toes but not by shoeing interval.^{9,22,25,33,39,46,55,56,58} Heel wedges and shoe composition (i.e., iron, steel, plastic, plastic-steel composite shoes, etc.) impacted vertical ground reaction force metrics.^{7,17,19,29,31,46} Pressure magnitude and distribution over the shoe and/or hoof surface were affected by both ground surface hardness and shoe configuration.^{33,37,38,42,52,55} Braking force changed with shoe-ground surface interactions represented by the friction coefficient in several studies.^{9,17,31} The metacarpophalangeal, proximal and distal interphalangeal, and third phalanx angles were impacted by the presence and shape of shoes.^{22,23,25,29,35,48}

3.6 | Limitations and knowledge gaps

While some reports did not include one or more signalment variables, age, weight, and/or breed, others included only one breed or less than five horses (71.74%), potentially limiting application of results to the general horse population (Table 5). Common study design limitations included those associated with data analysis and experimental design (65.22%) such as lack of treatment randomization, no untreated (unshod) or standard treatment control, or minimal or no statistical analysis (52.17%). Additionally, a fair number of studies stated a

TABLE 3 Study discipline, recording equipment, rider status, anatomical focus, and outcome measures.

Study	Discipline	Recording equipment	Rider (Y/N)	Anatomical focus	Main outcome measures
Al Naem et al. (2020) ⁴⁶	Kinetics	Sensor foil-based pressure measurement system	N	Forelimb hooves	Vertical force, hoof contact area, center of force, stance phase duration, breakover percent of stance phase
Amitrano et al. (2016) ⁹	Kinetics	Force platform	N	Forelimb hooves	Stance time, vertical force peak, vertical impulse, time of vertical force peak, braking force peak, braking force impulse, time of braking force peak, propulsive peak force, propulsive force impulse, time of propulsive force peak
Barrey (1990) ¹⁶	Kinetics	Instrumented open heel shoe	N	Forelimb hooves	Vertical force, impulse, minima, maxima, and slope, mean position and pathway of zero moment, velocity, stride frequency, stance phase duration
Caure et al. (2018) ⁴⁸	Kinematics	2D videography with hemispheric reflective markers	N	Right fore- and hindlimb joints	Joint angles, maximal protraction and retraction, area under the extension curve, stride length and duration, stance and swing phase duration
Chateau et al. (2004) ²²	Kinematics	Ultrasonic recording system, microphone markers attached to intracortical bone pins	N	Left distal forelimb	Palmar angle of the proximal and distal interphalangeal joints and dorsal angle of the metacarpophalangeal joint, positional angles of the hoof and third metacarpal bone, temporal stance variables
Chateau et al. (2006) ²³	Kinematics	Ultrasonic recording system, microphone markers attached to intracortical bone pins	N	Left distal forelimb	Palmar angle of the proximal and distal interphalangeal joints and dorsal angle of the metacarpophalangeal joint, positional angles of the hoof and third metacarpal bone, temporal stance variables
Clayton et al. (1991) ²⁴	Kinematics	2D cinematography	N	Forelimb hooves	Ratio of treated limb breakover time to control limb breakover time
Clayton et al. (2000) ²⁵	Kinetics, kinematics	Force platform, 3D optoelectronic motion recording system with photodiode markers	N	Distal forelimb joints	Ground reaction force and impulses, center of pressure, stride length and duration, stance and breakover time, limb protraction and retraction angles, maximal flexion of the coffin and extension of the fetlock and carpal joints, net joint moments and powers
Day et al. (2020) ²⁶	Kinematics	Inertial measurement units	N	Fore- and hindlimbs	Head, withers, sacrum, and tuber coxae vertical movement asymmetry
Duberstein et al. (2013) ³⁶	Kinematics	2D videography with reflective paint markers	N	Forelimbs	Step length, swing and stance times, maximum forelimb protraction and retraction, minimum and maximum elbow joint angles and minimum carpal joint angle, elbow range of motion, maximum

(Continues)

TABLE 3 (Continued)

Study	Discipline	Recording equipment	Rider (Y/N)	Anatomical focus	Main outcome measures
Eliashar et al. (2002) ²⁷	Kinetics, kinematics	Force platform, 3D videography with retroreflective hemispherical markers	N	Distal forelimb	fetlock extension, maximum height of the carpus, maximum hoof height, location of maximum hoof height, toe flight arc Stance time, breakover duration, distal interphalangeal joint moment arm, vertical ground reaction force, rate of decrease in vertical ground reaction force, peak force on navicular bone magnitude and time, angle between deep digital flexor tendon proximal and distal to navicular bone
Hagen et al. (2016) ³⁷	Kinetics	Sensor foil–based pressure measurement system	N	Forelimb hoof	Pressure distribution between the hoof solar surface and shoe and between the shoe and ground
Hagen et al. (2017) ³⁸	Kinetics	Sensor foil–based pressure measurement	N	Forelimb hoof	Pressure distribution between the hoof solar surface and shoe and between the shoe and ground
Hagen et al. (2021) ³⁹	Kinematics	Hoof-mounted inertial measurement unit sensor system	N	Fore- and hindlimb hooves	Breakover duration
Hagen et al. (2023) ⁴⁰	Kinematics	Hoof-mounted inertial measurement unit sensor system	N	Forelimb hooves	Landing duration, location and angle of initial contact
Harvey et al. (2012) ⁴⁴	Kinematics	2D videography with nitrocellulose lacquer and/or titanium dioxide circular marks	Y	Fore- and hindlimb hooves	Hoof slip distance, slip duration, stance duration
Horan et al. (2021) ⁴⁹	Kinematics	Smart phone inertial measurement units	Y	Girth	Craniocaudal, dorsoventral, medio-lateral axis displacement maxima and minima
Huguet et al. (2012) ⁴¹	Kinematics	2D videography with reflective paint circles	N	Forelimb	Stride length, fetlock extension, elbow and carpus minimum and maximum angles and range of motion, maximum hoof and carpus heights
Hüppler et al. (2016) ⁴²	Kinetics	Sensor foil–based pressure measurement	N	Forelimb hoof	Pressure distribution between the hoof solar surface and shoe and between the shoe and ground
Kai et al. (2000) ⁵⁰	Kinetics	Custom recording system composed of four load cells and three accelerometers between an aluminum plate and a stainless-steel plate	N	Forelimb hooves	Vertical ground reaction forces and temporal parameters, hoof accelerations

TABLE 3 (Continued)

Study	Discipline	Recording equipment	Rider (Y/N)	Anatomical focus	Main outcome measures
Keegan et al. (1998) ²⁸	Kinematics	3D videography with spherical retroreflective markers	N	Forelimb and head	Maximum fetlock and carpal extension and flexion and range of motion, maximum limb protraction and retraction, swing phase length, maximum hoof height during swing, swing phase length, head height maximum and minimum difference, temporal parameters
Kicker et al. (2004) ⁴⁵	Kinematics	3D videography with spherical markers	N	Distal forelimbs	Minimal virtual dorsal fetlock joint angle, stride occurrence time of the angle
Panagiotopoulou et al. (2016) ²⁹	Kinetics, kinematics	Force platform, 3D videography, fluoroscopes	N	Distal forelimb	Mean craniocaudal, mediolateral and vertical ground reaction forces, mean angle of flexion-extension for the proximal and distal interphalangeal joints
Panos et al. (2023) ³⁰	Kinematics	Inertial measurement units, 2D videography with colored duct tape markers	N	Hindlimbs	Subjective lameness, gait symmetry, hock angle and range of motion
Pardoe et al. (2001) ³¹	Kinetics, kinematics	Force platform, 3D videography with hemispherical retroreflective markers	N	Forelimb hooves	Slip time and distance, craniocaudal and vertical ground reaction forces, craniocaudal to vertical ground reaction force ratio
Paz et al. (2019) ⁴⁷	Kinematics	2D videography with round reflective markers	N	Forelimbs	Stride duration, stance phase duration, relative stance duration, breakover duration, swing duration, stride length, stride frequency
Peham et al. (2006) ³²	Kinematics	3D videography with spherical reflective markers	N	Distal hindlimb	Plantar combined proximal and distal interphalangeal joint angle, metatarsophalangeal, and tarsal joint angle
Reilly (2010) ⁴³	Kinetics	Sensor foil-based pressure measurement	Both	Forelimb hooves	Pressure distribution between the hoof solar surface and shoe
Riemersma et al. (1996) ¹⁸	Kinetics	Force platform	N	Forelimbs	Ground reaction force amplitude index and symmetry index, ground reaction force vector point of application and magnitude, distal interphalangeal joint torque
Roepstorff et al. (1999) ⁷	Kinetics, kinematics	Force platform, 3D videography with spherical, infrared-reflecting markers	Y	Fore- and hindlimb	Vertical and craniocaudal ground reaction forces, force point of application, fore- and hindlimb hoof, pastern, and fetlock, and carpal and tarsal joint angle, range of motion, and angular velocity, hoof angle and velocity

(Continues)

TABLE 3 (Continued)

Study	Discipline	Recording equipment	Rider (Y/N)	Anatomical focus	Main outcome measures
Rogers et al. (2007) ³³	Kinetics	Pressure plate	N	Fore- and hindlimb hooves	Pressure distribution between the shoe and ground surface, pressure temporal parameters, peak pressure, maximum vertical ground reaction force
Rumpler et al. (2010) ⁵¹	Kinematics	3D infrared videography with circular infrared-reflecting markers	Y	Forelimbs	Motion cycle duration, maximum hoof flight arc height, maximum potential energy, difference between maximum and minimum fetlock and carpal angles
Scheffer et al. (2001) ⁸	Kinematics	3D videography with reflective markers	N	Left distal forelimb	Mean hoof angle and maximum fetlock extension at midstance
Singleton et al. (2003) ³⁴	Kinematics	2D videography with reflective markers	N	Forelimbs	Shoulder, elbow, carpus, fetlock, and coffin sagittal plane net joint moments and powers, hoof flight arc
Sluiter et al. (2018) ¹⁹	Kinetics	Integrated pressure plate/force platform combination	N	Forelimbs	Temporal gait parameters, vertical impulse, peak vertical force, stance duration toe–heel index, toe–heel balance
Spaak et al. (2013) ⁵²	Kinetics	Integrated pressure plate/force platform combination	N	Hindlimbs	Vertical, craniocaudal, and transverse ground reaction forces, center of pressure shift peak and velocity
Stutz et al. (2018) ⁵³	Kinematics	Inertial measurement units	N	Forelimbs	Sagittal carpus, radius, and metacarpi range of motion, radius and metacarpi abduction-adduction range of motion, segment range of motion symmetry, stride duration, stride length, stride frequency, speed, limb phasing, diagonal asymmetry
Thompson et al. (1994) ⁵⁵	Kinematics	2D videography with circular reflective markers	N	Distal forelimbs	Stride length, stride frequency, stance duration, phalangeal and metacarpophalangeal joint angles
Van Heel et al. (2005) ⁵⁴	Kinetics	Integrated pressure plate/force platform combination	N	Fore- and hind hooves	Vertical ground reaction force, center of pressure location
Van Heel et al. (2006a) ⁵⁵	Kinetics, kinematics	Integrated pressure plate/force platform combination, 3D infrared videography with reflective markers	N	Fore- and hind hooves, right forelimb	Stance time, breakover duration, stride length, protraction and retraction angles, cumulative and peak indicative moment, center of pressure duration of and peak displacement, vertical ground reaction force, hoof placement symmetry, hoof-unrollment pattern, hoof angle

TABLE 3 (Continued)

Study	Discipline	Recording equipment	Rider (Y/N)	Anatomical focus	Main outcome measures
Van Heel et al. (2006b) ⁵⁶	Kinetics, kinematics	Integrated pressure plate/force platform combination, 3D infrared videography with reflective markers	N	Ipsilateral fore- and hindlimb	Stance time, breakover duration, relative breakover, protraction and retraction angles, fetlock and proximal hoof angles, landing symmetry, initial contact, midstance, heel lift, toe-off, duration of landing
Waldern et al. (2013) ⁵⁷	Kinetics, kinematics	Treadmill integrated force measurement system, 3D infrared videography with spherical reflective markers	Y	Fore- and hindlimbs	Stride duration, stride rate, stance duration, ipsilateral step duration, stride length, stance length, overreach distance, vertical limb and stride impulse, peak vertical force, average load distribution between fore- and hindlimbs, head height, dorsoventral movement of the caudal back, maximum fore-/hindlimb protraction and retraction angles, forearm angle around the elbow, vertical height of hooves and carpus, and time of maximal vertical height of forelimb coffin joint
Wang et al. (2021) ¹⁷	Kinetics	Force platform	N	Fore- and hindlimbs	Vertical and craniocaudal ground reaction forces and impulses, stance, braking, and propulsion time, coefficient of friction ratio, fore-hindlimb bodyweight distribution
Weishaupt et al. (2013) ⁵⁸	Kinetics, kinematics	Treadmill integrated force measurement system, 3D infrared videography with spherical reflective markers	Y	Fore- and hindlimbs, fore- and hind hooves	Stride rate, stride, absolute stance, absolute breakover, and relative breakover duration, overlap duration of tripedal or bipedal support
Willemen et al. (1996) ²⁰	Kinetics, kinematics	Force platform, accelerometer, 3D optoelectronic motion recording system with photodiode markers	N	Forelimbs	Ground reaction force magnitude and direction, position of the coffin joint relative to the point of ground reaction force application, fetlock and hoof wall angles and flight arcs, stride length and duration, maximum coffin joint moment
Willemen et al. (1997) ²¹	Kinetics, kinematics	Force platform integrated with a 3D optoelectronic motion recording system with photodiode markers	N	Right forelimb	Ground reaction force, stride length, stride duration, range of protraction and retraction, range of carpal and fetlock joint movement, maximal carpal and fetlock joint flexion, maximal fetlock joint extension, vertical displacement range of the hoof, fetlock, and carpus, maximal coffin joint moment, maximal fetlock joint moment

Abbreviations: 2D, two dimensional; 3D, three dimensional.

TABLE 4 Summaries of individual study findings.

Study	Findings
Al Naem et al. (2020) ⁴⁶	Heel elevation with a hoof cast with heel wedge shortened breakover, decreased the vertical force at toe during breakover, increased the vertical force and contact area in the heel, and moved the center of force from middle to heel
Amitrano et al. (2016) ⁹	Hoof boots and toe-extension shoes both increased stance duration; hoof boots increased time of braking peak force, increased sole length in contact with the ground and prolonged the deceleration phase of the stride
Barrey (1990) ¹⁶	The position of the resultant vertical force moved cranially during stance; the vertical component was not distributed uniformly over the whole hoof surface with greater mechanical loading caudally, especially on impact
Caure et al. (2018) ⁴⁸	Compared to open-heel shod fore- and hindlimbs, unshod hind with shod front limbs increased stifle, hip, and fore fetlock extension, forelimb shod conditions increased carpus and shoulder flexion, hind reverse shoes increased elbow and shoulder extension, and hind egg-bar shoes increased stifle and hip extension at walk and trot; more significant differences were observed in the proximal versus distal limb, and in the fore- versus hindlimb
Chateau et al. (2004) ²²	With versus without heel wedges, standing and bearing periods were longer and breakover was shorter because heel off was delayed, forward rotation of the hoof was increased during landing, forward rotation of the hoof was decreased during breakover, third metacarpal retraction was increased at heel off, maximal extension of the metacarpophalangeal joint was increased and delayed, maximal flexion of the proximal interphalangeal joint was increased at the beginning of the bearing phase and maximal extension was decreased, maximal flexion of the distal interphalangeal joint was increased and delayed, maximal extension of the distal interphalangeal joint was decreased, and the distal interphalangeal joint was less extended at heel off
Chateau et al. (2006) ²³	With egg-bar versus standard shoes, stance duration was decreased, breakover was shorter, time of heel off and maximal extension of the metacarpophalangeal joint and flexion of the distal interphalangeal joint were delayed, backward rotation of the hoof was decreased during landing, forward rotation of the hoof was increased during bearing, maximal flexion of the proximal interphalangeal joint was increased at the beginning of bearing, maximal flexion of the distal interphalangeal joint was increased, and maximal extension of the distal interphalangeal joint was decreased
Clayton et al. (1991) ²⁴	There was no effect of rocker-toe, rolled-toe, or square-toe shoes on the breakover ratio
Clayton et al. (2000) ²⁵	There was more coffin joint flexion with heel wedges leading to less energy absorbed across the joint in both forelimbs and smaller peak palmar coffin joint moment during second half of stance; heel wedges delayed onset of breakover; net coffin joint moment moved dorsally during beginning of stance in the compensating forelimb; tension increased in the extensor branches of the suspensory ligament and common digital extensor tendon on the dorsal side and decreased in the deep digital flexor tendon and its distal accessory ligament on the palmar side; there was no effect of heel wedges on lameness
Day et al. (2020) ²⁶	There was greater amplitude of the right tuber coxae when the lateral heel road nail was placed in the left hind shoe indicating a small increase in weightbearing and propulsion of the treated hindlimb
Duberstein et al. (2013) ³⁶	Retraction of the forelimbs was greatest when breakover was moved 1 inch back from the toe; minimum fetlock height at a trot was higher with all treatments that moved the breakover point caudally; as the breakover point moved caudally, protraction decreased at a trot, and retraction decreased at a walk and trot, step length decreased at the walk, elbow range of motion decreased at walk and trot, carpal angle increased at a walk, hoof height at the walk was progressively lower, fetlock extension decreased at a walk and trot, minimum fetlock height increased at a trot, swing time increased and stance time decreased, and swing to stance ratio increased at a walk
Eliashar et al. (2002) ²⁷	Shortening the breakover distance reduced the moment arm on the distal interphalangeal (DIP) joint which was reduced with both Natural Balance and quarter-clip shoes
Hagen et al. (2016) ³⁷	The size of the loaded area between the horseshoe and ground or between the horseshoe and hoof was not significantly different between standard and modified shoes on ground surfaces of concrete, rubber, hard sand, or deep sand; on firm ground, the lateral hoof regions were more loaded with a wide branch shoe; pressure on the hoof and shoe beneath a lateral side wedge was lower on penetrable ground

TABLE 4 (Continued)

Study	Findings
Hagen et al. (2017) ³⁸	The size of the loaded area between the horseshoe and ground decreased with wedges on concrete and rubber and between the shoe and hoof on deep sand; between the shoe and ground, pressure decreased on concrete, rubber and hard sand; pressure decreased between horseshoe and ground on concrete with rocker shoes; wedges and studs increased pressure on the toe and heels on firm surfaces; rocker shoes caused pressure peaks on the toe and high pressure on the quarters
Hagen et al. (2021) ³⁹	Heel wedges decreased breakover duration at a walk and trot compared to unshod or plain toe clip; plain toe clip increased breakover duration compared to unshod at a walk; rolled toe-clip and set-back quarter-clip shoes decreased breakover duration compared to plain toe-clip shoe at a walk; breakover duration was lower in hind hooves compared to front at a walk and higher at a trot while unshod
Hagen et al. (2023) ⁴⁰	Landing duration was increased by plain toe-clip, rolled toe-clip and palmarly placed quarter-clip shoes and all three enhanced initial contact location with decreased flat-footed landing compared to unshod at a trot; landing duration was longer for rolled toe-clip versus plain toe-clip shoes at a trot
Harvey et al. (2012) ⁴⁴	Addition of studs to the shoes decreased hoof slip distance in all four limbs; the slip duration of the trailing forelimb was shorter with compared to without studs; stance duration was longer with versus without studs in the leading hindlimb; without studs, hindlimbs slipped further than forelimbs, and trailing limbs slipped farther than leading limbs
Horan et al. (2021) ⁴⁹	Shoeing condition affected all displacement parameters except mediolateral minima for the horse; absolute differences were largest vertically with similar displacements while unshod and with aluminum racing plates compared to aluminum-rubber composite and steel shoes; shoe-surface interactions affected only the mediolateral axis minima and maxima and dorsoventral axis maxima of the horse
Huguet et al. (2012) ⁴¹	Compared to steel shoes, aluminum shoes resulted in higher minimum carpus angle and a lower maximum hoof height; carpus height, maximum carpus angle, and carpus range of motion were affected by shoeing duration
Hüppler et al. (2016) ⁴²	The size of the weightbearing surface affected pressure force distribution; the loaded area between horse shoe and hoof was lower with egg-bar shoes on deep sand; the loaded area between horse shoe and ground was lower with wide toe shoes on rubber and hard sand; pressure was reduced at the shoe toe and increased on the branches with open toe shoes on firm ground; pressure was increased at the toe and decreased on the branches on the shoe and hoof surfaces with open toe shoes on penetrable ground
Kai et al. (2000) ⁵⁰	Ground reaction force and acceleration measured in three dimensions with the custom device while horses walked, trotted, or cantered were similar to those reported from force platform and accelerometer data collection; results were reproducible
Keegan et al. (1998) ²⁸	Three weeks after balancing and shoeing, fetlock and carpal range of motion, and maximum carpal flexion and hoof height during the stride swing phase all increased in horses with navicular disease
Kicker et al. (2004) ⁴⁵	Compared to no support, two of the support boots reduced maximum fetlock extension, and one delayed the occurrence of maximal extension; all support boots reduced maximum extension at a trot compared to no support
Panagiotopoulou et al. (2016) ²⁹	The stainless-steel shoe shifted craniocaudal, mediolateral and vertical ground reaction forces at mid-stance; shod and unshod, proximal and distal interphalangeal joints were flexed from approximately 10% of stance until mid-stance with maximal joint extension occurring just before the hoof lefts the ground; at mid-stance the proximal interphalangeal joint was more extended while shod, and the distal interphalangeal joint was more extended while unshod
Panos et al. (2023) ³⁰	Shoeing decreased lameness scores from unshod and increased the maximum angle of both hocks and the minimum angle of the left tarsus compared to unshod
Pardoe et al. (2001) ³¹	Initial decelerative force during slip was lower with plastic versus rubber shoes; the horizontal to vertical ground reaction force ratio was lower with plastic versus steel shoes during slip

(Continues)

TABLE 4 (Continued)

Study	Findings
Paz et al. (2019) ⁴⁷	Laminitic horses had a reduced stride length and swing duration and a longer relative stance duration compared to unaffected horses; stride length was longer and immediately detectable with wooden shoes in laminitic horses compared to unshod
Peham et al. (2006) ³²	With 8° or 16° heel wedges, the plantar combined proximal and distal interphalangeal joint angle and metatarsophalangeal joint angle extension were reduced, and the tarsal joint flexion was increased at a walk and trot
Reilly (2010) ⁴³	Gait affected the distribution of force across the hoof without a rider; egg-bar shoes increased the force in the caudal half of the hoof and increased the force in the medial half of the foot compared to open heel shoes with a rider
Riemersma et al. (1996) ¹⁸	Time at which the position of the ground reaction force vector was halfway from the mid-stance position to its take-off position was different among all shoeing conditions, flat shoe, egg-bar shoe, heel-wedge, toe-wedge; the cranial shift of the ground reaction force vector began at about 70% of the stance phase for the flat and egg bar shoes, at 60% with the toe-wedge, and at 80% with the heel-wedge; the heel-wedge increased and toe-wedge decreased torque during the first half of the stance-phase
Roepstorff et al. (1999) ⁷	Iron shoes increased maximum vertical ground reaction force; during initial stance, the coffin and fetlock joints rotated more rapidly in the forelimb and less rapidly in the hindlimb while unshod; initial horizontal loading at the hoof was lower while unshod in fore- and hindlimbs; there was a backward tilting of the forelimb hoof during the middle part of the stance phase while unshod
Rogers et al. (2007) ³³	The egg-bar shoe had less peak pressure at the heel and across the entire shoe compared to the standard shoe; the 6° wedge shoe had greater loading on the lateral heel and promoted earlier breakover at the toe; egg-bar and wedge shoes increased total stance time compared to the standard shoe; landing with shoes was predominantly from lateral to medial; the highest peak pressure was found in the toe while the lowest peak pressure was in the heel with shoes
Rumpler et al. (2010) ⁵¹	The height of the arc of the forehoof flight and maximum potential energy were increased with speed and weighted boots; higher weights and faster speeds were correlated with increased flexion of the forelimb fetlock and carpal joints
Scheffer et al. (2001) ⁸	There was forward rotation of the normal or egg-bar shod hoof on soft track surfaces that was highest on sand; the effect of heel wedges on hoof forward rotation was always greatest among shoes and similar on a hard track surface; maximum fetlock extension was lowest on a soft surface, and the effect was most pronounced with heel wedges and least with normal shoes
Singleton et al. (2003) ³⁴	Flight arc of the coffin joint tended to be higher and peaked later while shod with egg-bar and flat shoes versus unshod; during early swing phase, the peak value of the net joint moment was significantly higher while shod versus unshod in all joints except the shoulder; the same was true for late swing phase except the shoulder peak moment was higher with flat shoes versus unshod; during early swing phase, both flat shoes and egg-bar shoes were associated with significant increases in energy generation on the cranial aspect of the elbow and energy absorption on the dorsal aspect of the other joints; in late swing phase, the net joint moment moved to the caudal/palmar aspect of all joints; peak values of the caudal/palmar net joint moments in late swing phase were higher for shod conditions at all joints; energy generation on the caudal aspect of the elbow and energy absorption on the palmar aspect of the carpal and fetlock joints were larger for shod conditions
Sluettjens et al. (2018) ¹⁹	Vertical impulse and peak vertical force decreased immediately after application of the moldable frog-supportive shoe at the walk, and increased significantly 72 h after shoe application at a walk and the trot in normal and obese ponies; obese ponies had decreased loading of the toe area; stance duration toe-heel index and toe-heel balance curves were lower for unshod obese ponies at walk and trot but were comparable between groups after application of the frog-supportive shoes
Spaak et al. (2013) ⁵²	Compared to the toe-clipped shoe, the center of pressure at toe-off was positioned less dorsally with shoes set back, side clipped shoes with and without a rolled toe had more lateral orientation of the center of pressure at toe-off, and a side clipped shoe with a rolled toe had a smoother and longer shift of the center of pressure

TABLE 4 (Continued)

Study	Findings
Stutz et al. (2018) ⁵³	The presence of a shoe had a significant effect on the majority of measured kinematic (spatial and temporal) variables in the forelimb; unshod horses had a shorter stride duration, shorter stride length, and higher stride frequency, and the maximum point of protraction and retraction was earlier than while shod; while shod horses had an overall larger sagittal range of motion of the forelimb; there was a greater sagittal range of motion of carpi and radii and smaller range of motion of metacarpi overall on a soft ground surface
Thompson et al. (1994) ³⁵	The dorsal metacarpophalangeal joint angle was lower and the phalangeal joint angle higher with caulk shoes in the sagittal plane; both angles were lower with caulk shoes in the transverse plane
Van Heel et al. (2005) ⁵⁴	In the hind hooves, the center of pressure location shifted in the dorsal direction 8 weeks after shoeing, the forehooves kept unrolling along the sagittal hoof axis, while in hind hooves, there was a shift in unrolling toward lateral
Van Heel et al. (2006a) ⁵⁵	Breakover was less abrupt and had a lower moment with the rolled versus flat toe; the center of pressure shifted more in the sagittal axis with the rolled toe shoe
Van Heel et al. (2006b) ⁵⁶	Compensation to partially counteract the shift of the center of pressure under the hoof from hoof growth and wear was achieved through an increase in the dorsal angle of the metacarpophalangeal or metatarsophalangeal joint and a decrease in the dorsal angle of the hoof wall and metacarpophalangeal or metatarsophalangeal joint; an additional compensatory mechanism may exist in the hindlimb that resulted in an increase in the proximal hoof angle
Waldern et al. (2013) ⁵⁷	Gait quality was improved with high, long shod front hooves with a lower stride rate, a longer stride length and a higher, but not wider, forelimb protraction arc; there was an increase in maximal protraction angle in the hind limbs at all three gaits, decreased head range of motion at the tölt, longer stance duration and higher fore- and hindlimb vertical impulse at a tölt and trot, and smaller overreach distance at a trot with high, long shod front hooves
Wang et al. (2021) ¹⁷	Compared to unshod, the longest stance time was with standard open-heel shoes, the greatest increase in forelimb peak force was with plastic-steel composite shoes, and the increase in hindlimb peak braking force was, from highest to lowest, with plastic-steel composite shoes, a thin layer of tungsten carbide, and low profile–high surface area calked shoes; the highest coefficient of friction was with plastic-steel composite shoes in fore- and hindlimbs
Weishaupt et al. (2013) ⁵⁸	High hooves with long toes reduced stride rate, prolonged breakover duration, reduced the cadence of all gaits, and changed inter- and intralimb coordination
Willemen et al. (1996) ²⁰	There were no significant differences between the two shoe types in any measured variables to evaluate duration and ease of breakover or the proximity of breakover to the center of the toe including stride length, stride duration, stride relative stance duration, hoof flight arc and angular velocity during breakover, and coffin joint moment
Willemen et al. (1997) ²¹	Compared to unshod, shoeing resulted in larger stride duration and length, shorter stance duration, decreased protraction and retraction range, decreased swing phase retraction, greater carpal and fetlock joint range of motion, larger fetlock maximal flexion, and higher maximal hoof, fetlock and carpus flight arc height

need for further investigations to confirm findings, and/or acknowledged limits of the methods, experimental conditions, or equipment (32.61%). Some reported outcomes were highly customized for study conditions that would be difficult to reproduce for further testing or validation, and others did not include results for outcomes described in the methods (60.87%). Inadequate instrument sensitivity and/or durability, inconsistent signal or detector positioning, and low outcome specificity were also identified as limitations (30.43%).

Conditions that were not consistently included in studies were conformation or hoof or limb morphology. Additionally, the effects of lameness, and hoof or limb pathology on shoe effects on gait kinetics and/or kinematics were infrequently considered. Rarely were shoe configuration effects evaluated on all four limbs. Finally, as mentioned above, outcome measures varied widely among studies, and occasionally, were highly customized, limiting the ability to validate or extend individual study findings.

TABLE 5 Study limitations.

Parent group	Subgroups	Records (%)
Participants	- Small sample size - Single breed - Missing age, weight, and/or breed	71.74
Data analysis and experimental study design	- Minimal/no statistical analysis - Lack of randomization - No untreated or standard treatment control - Investigators aware of treatments - Experimental modifications needed - Validation of results required	65.22
Results and data reporting	- Highly specific outcomes - No results for outcomes described in methods	60.87
Instrumentation and data collection	- Inadequate data recording equipment sensitivity/durability - Inconsistent signal or detector positioning - Low outcome specificity	30.43

3.7 | Geographic distribution of the studies

Most of the studies were performed in European countries, Netherlands (23.9%),^{8,18–21,25,33,52,54–56} United Kingdom (15.2%),^{26,27,29,31,44,49,51} Germany (13%),^{37–40,42,46} and France (8.7%),^{16,22,23,48} or in the United States (19.6%, Figure 3).

4 | DISCUSSION

This scoping review includes a comprehensive summary of the available, peer-reviewed literature surrounding the effects of shoe configuration on equine gait kinetics and kinematics. It is evident that there are both global interest and investigative contributions, and that studies have evolved with emerging technology and an expanding knowledge base. However, studies tend to be concentrated in some geographical areas. Limitations inherent to equine studies that are associated with the size, speed, and locomotion forces of the species are apparent. Similarly, the need to configure areas and systems for data collection can lead to customized outcomes that are unique to individual investigations, though kinetic variables tend to be more highly conserved among studies than kinematic. Effects of shoe modifications on some gait parameters like breakover are relatively well aligned among studies.

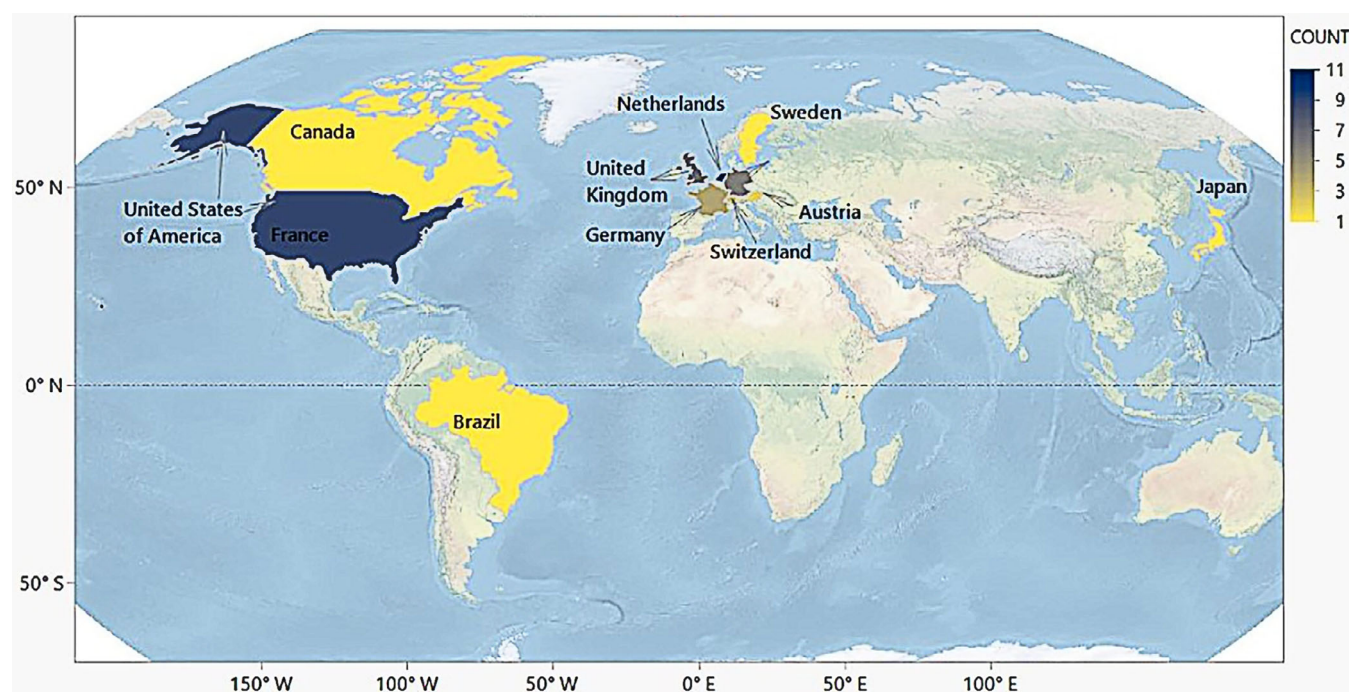


FIGURE 3 Simple earth map showing study distribution among countries. The color indicates the number of each study in each country ranging from 1 (yellow) to 11 (dark blue).

Studies that utilize popular, commercially available shoe configurations will be helpful to confirm that they have the intended effects on gait and force distribution. For the best opportunity to validate and extend existing work, consistencies in trial performance and outcome measures will be important. Further, broader inclusion of diverse breeds and/or consideration of the interaction between conformation, morphology, and shoe effects will extend the impact of study findings. Among studies, shoe modifications designed to alleviate discomfort associated with pathologic conditions like laminitis or navicular disease, hoof damage, or conformational abnormalities are rare compared to those focused on performance or load distribution. Work in these areas will be valuable to protecting and extending comfortable movement of the general horse population.

Limitations of this scoping review include the investigative focus and specificity of the research questions determined by the authors a priori. Though this ensured consistency in study selection and evaluation, some bias and/or omission in the data collection and evaluation process could not be entirely avoided. Four distinct, established databases and numerous search terms were used in the initial study selection, but it is still possible that not all studies were identified. Failure to include author-acknowledged limitations in available literature influenced those identified in this review as some interpretation by the authors was required. Reporting limitations within individual reports will minimize this effect in the future.

5 | CONCLUSION AND CLINICAL SIGNIFICANCE

A comprehensive reference for the future design and conduct of studies on the effects of shoes on equine kinetics and kinematics is available in this scoping review. Consistency in methods and outcome measures, utilizing popular and novel shoe designs and appropriate controls, expanding the diversity of study population, and inclusion of limb and hoof morphology, as well as pathology will augment the impact of ongoing research efforts. This will contribute to precision and reliability of evidence-based findings about shoeing effects on equine kinetics and kinematics for future systematic reviews and meta-analyses.

AUTHOR CONTRIBUTIONS

Aoun R, PhD: Conceived and designed the study, collected data, performed the analysis, wrote the manuscript draft, created figures, revised manuscript drafts, approved the final version of the manuscript. Takawira C, MS: Collected data, reviewed and provided feedback on the manuscript drafts, approved the final version of the manuscript. Lopez MJ, DVM, MS, PhD, DACVS: Conceived and designed the

study, collected data, reviewed, revised, and edited manuscript drafts, approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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