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*This review accompanies the relevant episode of the Cutting Edge veterinary podcast. In each episode of this podcast, 3rd year students in the University of Calgary's veterinary medicine program fill you in on the most up-to-date literature and evidence-based practices on topics that matter to you, the practising veterinarian.*

# The Present and Projected Value of Kinetic Data in Equine Gait Analysis

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## Introduction

Historically, objective gait analysis has been highly sought after in equine medicine and research to confirm conclusions made with the naked eye and to draw new ones. There are two divisions of dynamics within the study of equine biomechanics: kinetics, which considers how forces cause motion, and kinematics, which examines motion exclusively without the assessment of force. There is an abundance of research in equine medicine and science using kinematic analysis, where features of gait have been assessed by visual evaluation in terms of distance, time and angular measurements[1]. This is what is being applied currently in clinical settings. A limitation to kinematic analysis is that the data is temporal and spatial and only measures the geometry of movement without considering the forces that cause the movement. Studying the forces that cause motion along with describing the motion allows for greater understanding of the equine gait than kinematics alone.

Kinetic analysis measures both internal and external locomotor forces on the body. Muscular forces are translated into rotational movements of the limb segments, ultimately leading to motion[1]. Using kinetics to analyze equine locomotion requires technology quantifying ground reaction forces (GRFs)[1]. Equine kinetic gait analysis can be applied in many ways, including physiological gait analysis, lameness evaluation, and scientific research. Currently, no objective gait analysis can regionalize lameness within a limb, provide differentials based on where it is, or characterize the details of the stride. If we had data which could be gathered from accurate kinetic analysis, especially when combined with kinematic analysis, steps could be taken toward answering these questions with objective gait analysis.

## Kinematic Quantification Methods

The field of kinematic gait assessment is more familiar in the veterinary field than kinetics since there are devices that can be used in clinical practice such as the "Lameness Locator" to aid the veterinarian in lameness diagnosis. Kinematic tools commonly utilize optical motion capture and inertial measurement units which quantify the spatial movement that is qualitatively visualized when assessing movement with the human eye. The captured data includes temporal (stride duration and limb coordination), linear (stride length and limb flight paths), and angular variables (rotational motion of joints and limbs).[1] The advantage of kinematic assessment of equine locomotion is the availability of the products. With new technology, anyone could take a video of a horse moving on a mobile phone and have this translated into data that could be clinically evaluated by a veterinarian. A less familiar quantification method of gait assessment is kinetic analysis that will be described throughout the remainder of this review.

## Kinetic Quantification Methods

Ground reaction force (GRF) is the force that occurs as the hoof strikes the ground and is equal in magnitude to the force that the ground exerts against the hoof in the opposite direction[2]. GRF determines the body's acceleration and direction, and it is present during all parts of the stance phase (when the hoof is in contact with the ground). Triaxial force measurement quantifies the forces in the x, y, and z axes, and can be demonstrated by measuring the three dimensional GRFs (vertical, longitudinal/craniocaudal, and transverse/mediolateral). GRFs can be plotted on a force-time graph and can be normalized to body mass to compare forces between horses in N/kg[1] or normalized as a percentage of stance duration. The magnitude of the vertical component of the ground reaction force fluctuates with speed, gait, limb, and body mass. Longitudinal GRFs measure deceleration and acceleration of the horse and it considers posture and balance[2]. The transverse component increases with turning motion and when moving in a straight line it is directed medially with a small magnitude[1]. Together, these three forces make up the triaxial measurements, also considered the three degrees of freedom, which is half of the six quantifiable movements of a body in space. Ground reaction forces can be quantified with force plates, instrumented treadmills, force shoes, or pressure plates.

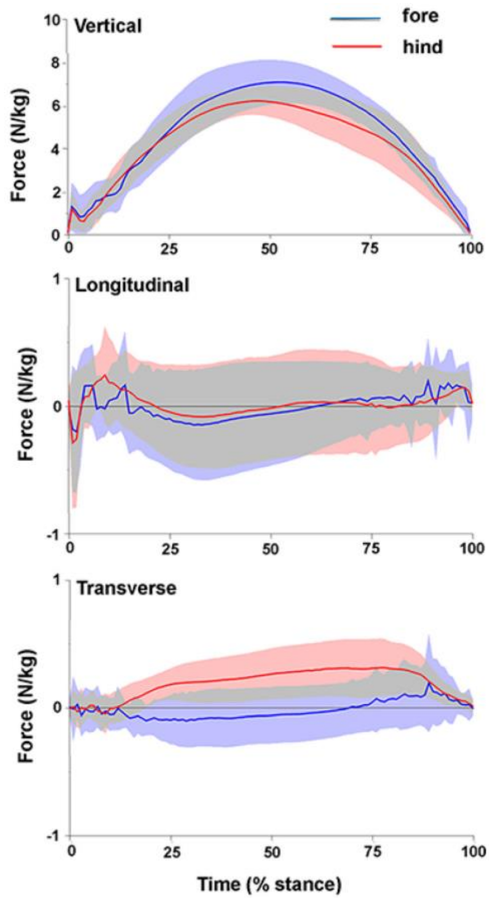


Figure 1. Example of force-time graphs for the vertical, longitudinal, and transverse GRFs. Data collected via embedded force plates. (Clayton HM, Hobbs SJ. Ground Reaction Forces of Dressage Horses Performing the Piaffe. Animals. 2021 Feb 8;11(2):436. doi:10.3390/ani11020436).

## Devices

Force plates are made of steel, contain transducers (sensors) and are usually mounted on a hard surface such as cement and covered with rubber, sand, or some other non-slip substance. The transducers can be uniaxial or triaxial and they convert mechanical load (weight, pressure) into an electrical signal. The force created by a horse as it steps onto the force plate is recorded as an electrical signal of a change in voltage or resistance depending on the transducer type. These signals can then be translated into a force measurement. The resulting measurements include three dimensional force magnitude, stance phase duration, center of pressure, and impulse[1]. A limitation is forces that are applied when multiple hooves contact the plate at the same time can not be separated into their respective individual values[1]. To capture the individual forces acting on each separate hoof during a single stride of quadrupedal gait, each hoof must independently land on a separate force plate. This is difficult to achieve when considering traditional force plates. If individual force plates could be mounted on each hoof, independent GRF data could be collected for each hoof over multiple stride cycles, providing a new method to quantifying quadrupedal gait.

Pressure plates or mats are possibly a clinically applicable alternative to force plates which are restricted to research environments due to the extensive setup (not portable) and materials required. Pressure plates are portable and measure the distribution of pressure of the hoof throughout the stance phase[3]. A study comparing pressure and force plates found that a pressure plate system can be used to evaluate kinetic symmetry in horses but does not compare to the high accuracy of force plates; therefore, it can not replace force plates in research aspects, and further calibration with force plates is required to decrease quantification errors before the use in clinical practice[3].

A growing field in equine gait analysis is wearable technology. Instrumented force shoes or boots are the most experimental wearable for kinetic gait analysis. They have similar principles to force plates but are portable, can be used on multiple surfaces, and obtain measurements from multiple limbs[1]. A further explanation of force shoes is provided later in the review.

## Functional Symmetry

Kinetic quantification has been used multiple times in multiple studies on functional consequences of forelimb asymmetry in riding horses[4]. One study discusses the importance of left-right symmetrical distal limb conformation in successful performance [4]. They highlight the hypothesis that asymmetric feet are an important contributing factor to the development of lameness. The study found differences in vertical force and braking force between uneven forefeet, which were said to imply either an asymmetrical loading pattern without a pathological component or a subclinical lameness as a result of pathological development in the steeper foot[4].

This study is one example of an attempt to relate the concept of symmetry to soundness/lameness [4]. Many studies such as this highlight the difficulty among researchers and clinicians to agree when defining where the overlap occurs between asymmetry and lameness. Deciding how asymmetric is 'too asymmetric' is an important consideration as it applies to clinical situations such as subtle lameness, use of symmetry measurement in pre-purchase exams, and other assessments. Users of technology, kinematic technology currently, need to have a solid understanding of its strengths and limitations to draw meaningful conclusions. Lack of understanding in this area is an issue, which is why better and clearer measurements; kinetic measurements, are needed in the future.

## Lameness diagnosis

The study of kinetics can be applied to diagnose lameness in a research setting using force plates or shoes. A 2018 review discussed the limitations of subjective visual lameness diagnosis[5]. These were limitations due to the perception of asymmetry, memorization and bias, and there is consistently low agreement between observers[5]. While there are current applications of kinematics in the clinical setting for objective lameness assessment, kinetics is continuing to be explored in this aspect to allow for more sensitive measurement of physical variables (such as force) associated with gait. These variables and their gait associated patterns can be used to determine features of gait where normal and abnormal patterns have been implied to derive information regarding the presence or absence of lameness or abnormal gait. Kinetic data from force plates shows that decreased peak vertical ground reaction force (pVGRF) can be a measurable result of a sore horse putting less weight on the affected limb[6]. Currently, kinetic methods for objectively analyzing gait are restricted to laboratory conditions due to the complex data collection[5].

Laminitis is a common painful inflammatory condition of the hoof that causes lameness. Kinetic data has determined that maximum force on the horse's toe occurs during the breakover phase (when the hoof starts to leave the ground) and this is when a horse with laminitis will feel the most pain[7]. A 2020 study considered if the application of a supportive orthopedic heel wedge would alleviate any lameness or pain of laminitic ponies[7]. The authors found that elevating the heel decreases the force on the toe during the breakover phase and therefore provides supportive therapy in acute laminitis cases[7]. This is an example of how kinetics can be applied to research therapies for lameness in horses.

Ataxia can look similar to lameness but is a gait abnormality due to a diseased spinal cord or brain, and subtle disease can be difficult to distinguish from a musculoskeletal issue on visual assessment alone. A 2009 study concluded that force plates can be used to help clinically evaluate the difference between ataxia and hindlimb lameness[6]. The authors found that the vertical force peak was decreased in the sore hindlimb only of lame horses; whereas ataxic horses had an increase in all four limbs' lateral force peak[6]. Thus, it was inferred that kinetics can be used to objectively quantify asymmetries associated with musculoskeletal or neurological conditions.

### Therapeutic Research

Though it has yet to be widely applied in clinical settings, kinetic evaluation of equine locomotion has been useful in research to draw conclusions on the effects of therapeutic treatments. One study seeking objective assessment of gait in xylazine-induced ataxic horses analyzed force plate data to quantify absolute differences between consecutive center of pressure (COP) locations to indicate postural control activity[8]. This particular study also used kinematic data collected via accelerometer measurements on horses walking on a treadmill. All horses in their study developed a dose-dependent ataxia with xylazine administration with COP and path length indices changing significantly[8]. In their conclusions, they highlight the importance of the findings from the COP analysis[8]. The effects of sedation with xylazine on COP displacement found in this study were found to align with clinical observations of ataxic horses, showing the value of quantifying these movement patterns using kinetics to reduce observer bias in diagnosing ataxia[8].

Another study used force plate measurements to titrate the dose of firocoxib to reduce chronic lameness[9]. They used a force plate on the most lame front limb at a trot and compared pretreatment peak vertical force (PVF) to post-treatment PVF and lameness grade in sixty-four horses with chronic lameness due to presumed osteoarthritis. Statistical analysis of the change in PVF from baseline in their treatment groups produced found no significant difference in the improvement of lameness between the dosage of 0.25mg/kg and 0.1mg/kg[9]. Their conclusion was that 0.1mg/kg can be the effective dose of firocoxib to reduce chronic lameness due to presumed osteoarthritis[9].

The conclusions of the two studies discussed above and many other similar studies are examples of the potential of kinetic evaluation to expand veterinary knowledge on the usefulness of therapeutic treatments. Compared to kinematics, kinetic gait analysis with accurate force measurement is very sensitive and able to detect subtle changes in gait associated with timing and administration of medication or other factors. This is more sensitive than using kinematics alone, and potentially much more sensitive if combined with kinematics.

## Clinical Implications

As described earlier, subjective gait analysis does not produce reliable or agreeable results between observers, regardless of clinician experience. A paper on evidence-based lameness detection highlights the consensus among studies suggesting that subjective evaluation of lameness by one individual should not be the gold standard to evaluate severity[10]. Furthermore, confounding factors such as temperament, conditioning, fortitude, and individual animal variation make it difficult to know what to attribute a horse's recovery from lameness to[10]. Adding objective lameness analysis practice to the traditional subjective visual assessment would help to mitigate these factors so that veterinarians can accurately record the progression and severity of lameness and effectively communicate with other practitioners and clients[10].

Adding the kinetic study of gait is imperative for more reliable lameness diagnosis compared to kinematic study alone as it explains motion rather than simply describing it[10]. An important issue to discuss, however, is kinetic analysis is more difficult to capture and interpret than kinematic analysis[10]. It takes more advanced data collection, analysis and specific knowledge to interpret the findings from kinetic methods of quantification. This means oftentimes, the data collected is only useful to the extent that a clinician can interpret it, which is a main issue with the more popular kinematic analysis as well.

For example, as described earlier, interpretation of force plate data generally uses a decrease in mean peak vertical ground reaction force (pVGRF) to infer lameness[10]. This is not always the case, however, as some conditions have been shown to cause a change in the shape of the VGRF signal rather than a decrease in the mean value[10]. To draw meaningful conclusions, a clinician would need to understand that the VGRF curve changes do not always differentiate soundness from lameness. Instead, the shape of the VGRF curve can contain information about limb structures during different phases of stance. With further interpretation, the shape of the VGRF curve has the potential to assist in localization of lameness within an affected limb[10]. If a clinician's knowledge was limited to the use of decreased mean pVGRF to diagnose lameness, this could lead to misdiagnosis of normal variation as lameness. Furthermore, these measurements are often of a single footfall on a force plate, measuring consecutive quadrupedal strides would provide much more information if it were possible.

## Instrumented Horseshoe

An upcoming area in kinetic research is focused on developing an instrumented horseshoe that measures GRFs that would not require the use of a force plate. This could allow the application of kinetic gait analysis in clinical settings by applying force measuring horseshoes to the individual horse being assessed. The shoe also quantifies forces for multiple consecutive strides whereas the force plate is typically one stride. In a 2009 study, authors created an aluminum horseshoe that contained piezoelectric force sensors to determine 3D GRFs and used it on one horse to assess accuracy[11]. However, care must be taken when analyzing the results of a dynamometric horseshoe (DHS) as different surfaces cause different output values, specifically center of pressure[11]. A 2010 study continued the research on a DHS considering the application of this shoe in riding and jumping instances[12]. With both studies, there is still need for further improvements for a more accurate and reliable shoe, and for more meaningful and reliable methods of interpretation of the large quantities of data acquired from this system.

## Conclusion

There are multiple applications for the study of kinetics in equine locomotion research and sports medicine. Analyzing forces with kinetics is a more direct method to assess lameness compared to kinematics. A lame horse will put less weight, and therefore less force, on the sore limb providing a direct quantifiable measurement for this soreness. Kinematics provides an indirect method of objective motion analysis where movement changes as a result of putting less weight on the lame limb; thus, the results are more variable compared to force measurement. When effectively interpreted, kinetic gait analysis has the potential to increase our understanding of functional symmetry and therapeutic effects in the literature, and aid practitioners in the diagnosis and monitoring of lameness. There are also potential opportunities for greater understanding of the equine gait by combining the use of kinetic and kinematic methods. It is difficult to assess movement using one method without the other. Kinetic and kinematic data combined provide a description and explanation of motion, allowing for a more complete picture of equine gait to be captured. Development of new wearable technologies and the integration of kinetic and kinematic data will result in further understanding of equine motion and there is good evidence to suggest the value of equine practitioners developing their knowledge on the subject. Veterinarians should recognize the opportunity that these technological advancements provide and strive to understand them and the principles behind them when looking to integrate objective gait analysis into their practice.

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## REFERENCES


1. Back W, Clayton H. Equine Locomotion. 2nd ed. Edinburgh: Saunders Elsevier; 2013. p. 41-46.
2. Clayton HM, Hobbs SJ. Ground Reaction Forces: The Sine Qua Non of Legged Locomotion. Journal of Equine Veterinary Science. 2019 May;76:25–35.
3. Oosterlinck M, Pille F, Huppes T, Gasthuys F, Back W. Comparison of pressure plate and force plate gait kinetics in sound Warmbloods at walk and trot. The Veterinary Journal. 2010 Dec;186(3):347–51.
4. Wiggers N, Nauwelaerts SLP, Hobbs SJ, Bool S, Wolschrijn CF, Back W. Functional Locomotor Consequences of Uneven Forefeet for Trot Symmetry in Individual Riding Horses. Ambrósio CE, editor. PLOS ONE. 2015 Feb 3;10(2):e0114836.
5. Serra Bragança FM, Rhodin M, van Weeren PR. On the brink of daily clinical application of objective gait analysis: What evidence do we have so far from studies using an induced lameness model? The Veterinary Journal. 2018 Apr;234:11–23.
6. Ishihara A, Reed SM, Rajala-Schultz PJ, Robertson JT, Bertone AL. Use of kinetic gait analysis for detection, quantification, and differentiation of hind limb lameness and spinal ataxia in horses. Journal of the American Veterinary Medical Association. 2009 Mar;234(5):644–51.
7. Al Naem M, Litzke LF, Geburek F, Failing K, Hoffmann J, Röcken M. Effect of heel elevation on breakover phase in horses with laminitis. BMC veterinary research [Internet]. 2020 Oct 1;16(1):370.
8. Nout-Lomas YS, Page KM, Kang HG, Aanstoos ME, Greene HM. Objective assessment of gait in xylazine-induced ataxic horses. Equine Veterinary Journal. 2016 Jul 23;49(3):334–40.
9. Back W, Macallister CG, Heel MCV, Pollmeier M, Hanson PD. The use of force plate measurements to titrate the dosage of a new COX-2 inhibitor in lame horses. Equine Veterinary Journal. 2009 Mar;41(3):309–12.
10. Keegan KG. Evidence-Based Lameness Detection and Quantification. Veterinary Clinics of North America: Equine Practice [Internet]. 2007 Aug;23(2):403–23
11. Chateau H, Robin D, Simonelli T, Pacquet L, Pourcelot P, Falala S, et al. Design and validation of a dynamometric horseshoe for the measurement of three-dimensional ground reaction force on a moving horse. Journal of Biomechanics. 2009 Feb;42(3):336–40.
12. Robin D, Chateau H, Jacobs F, P. Estoup, Holden L, S. Falala, et al. Suitability of a dynamometric horseshoe for the recording of the ground reaction forces on ridden horses. Computer Methods in Biomechanics and Biomedical Engineering. 2010 Sep 1;13(sup1):129–31.