How to measure lameness with objective methods and how you typically decipher compensatory patterns.

Lameness -a clinical sign

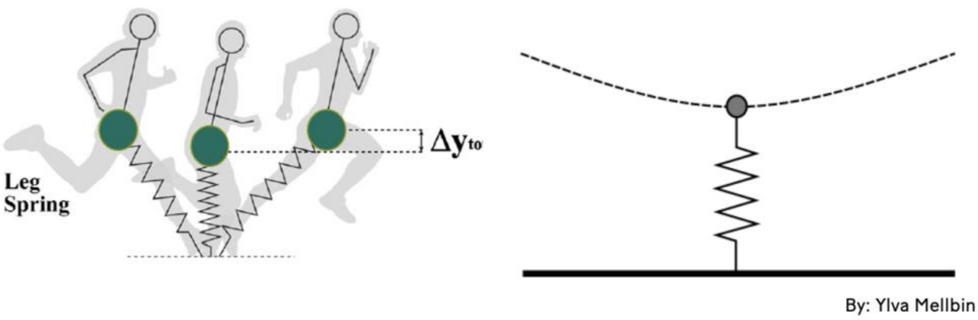
The term 'lameness' isn't always used consistently in scientific literature. While some consider any motion asymmetry to equate to lameness, regardless of the cause, others restrict the term to instances where an orthopaedic disease or a dysfunction is the root of the gait abnormality. In the following talks we adhere to the latter, by using the definition: **Lameness is a gait alteration due to a structural of functional disorder in the locomotor system**.

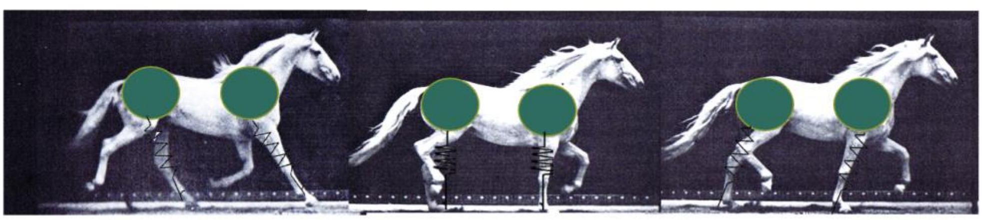
By using this terminology, we acknowledge that **lameness is a clinical sign** of disease or dysfunction and therefore not a diagnosis in itself. This distinction is essential for the following discussion of biomechanical approaches to measuring lameness.

Lameness isn’t just a single, isolated visual cue. It is a complex clinical sign, involving multiple body segments resulting in body behaviors that indicate pain or dysfunction. But, luckily biomechanical research has decomposed important and reliable motion descriptors of lameness, that can be measured with a high precision at the trot.

Biomechanical methods to measure lameness at the trot

For decades, biomechanical research sought a reliable method to measure lameness in horses. Early attempts in the 1970s, focusing on limb motion [1], proved unsuccessful. However, in the 1990s, researchers discovered that tracking the vertical movement of the head and pelvis offered a reliable way to detect lameness [2]. By analysing how these segments drop during the stance phase and how each diagonal limb pair propels them upward, two asymmetry values per stride can be calculated [3]: impact and push-off asymmetry. These Vertical Motion Asymmetry (VMA) measurements in the head and pelvis correlate strongly with vertical limb loading [4], explained by the spring-mass model of running. In this model, the body mass compresses the limb like a spring with each step, followed by an upward and forward push after mid-stance. The trajectory of the body mass takes the form of a wave for each step, going from high to low to high. (See image below.)





The spring-mass model of running. The circles represent the body mass acting on each limb pair. The legs are thought of as metal springs that compress during the mid-stance phase. The body mass trajectory takes the form of a wave per step and hence a double wave per full stride.

Standing on solid scientific ground, VMA measurements have been used extensively for the past 15 years in clinical practice and research to objectively assess lameness [5-7]. VMA measurements have proven to be more sensitive than human observation for detecting early signs of lameness [8]. But the specificity in relation to disease is a more complex matter that will be explored in a later talk.

Vertical motion asymmetry parameters

Head asymmetry

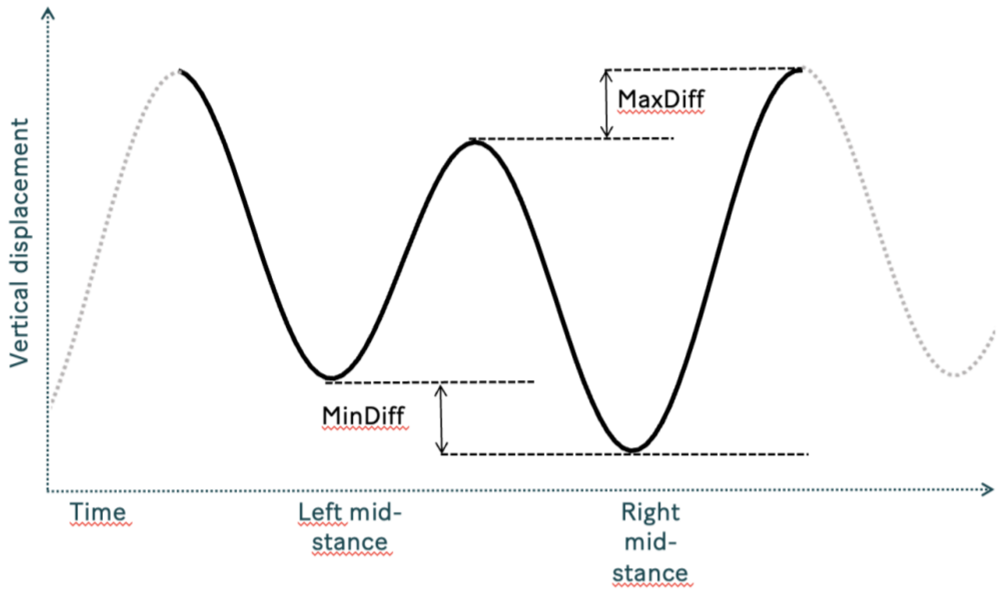
During trot the head and pelvis in sound horses have a sinusoidal movement pattern with two minima and two maxima per stride. The minima occur during the two stance phases of the forelimbs and the two maxima in the suspension phases after push-off. The head nod is commonly described in forelimb lame horses as a reduction in vertical movement of the head during the stance phase of the affected forelimb reaching a lower minimum position at mid-stance of the sound limb stance compared to lame limb mid-stance (HDmin). A difference between the two maximum positions (HDmax) is also commonly seen in forelimb lame horses. Commonly used symmetry measures is therefore HDmin and HDmax for forelimb lame horses.

Mid-pelvis asymmetry

Hindlimb lameness has been shown to be more difficult to assess compared to forelimb lameness [9-10]. The reason could be the smaller vertical movement amplitude of pelvis compared to the head in lame horses and lack of knowledge of the most sensitive pelvic motion features for lameness detection. Mid-pelvis shows a similar sinusoidal vertical motion pattern during trot as the head with similar changes in movement symmetry during hindlimb lameness. Differences in vertical displacement between the two minima (PDmin) indicate an impact lameness during first half of the stance phase whereas differences between the two maxima (PDmax) indicate a push off lameness during the second half of the stance phase [11]. To detect these changes in movement symmetry it is important to have a point of reference in the background to compare the two lowest and two highest positions of the pelvis against. In a study on the effect of speed on the visual assessment of lameness the authors found that the faster the horse trotted on a straight line the lover was the lameness graded even though motion asymmetry did not change [12]. The reason is probably the limitation of our vision.

Hip hike

The movement symmetry of the two tuber coxae (hips) can also be used for lameness assessment in the hind limbs. In a sound horse, showing a similar amount of movement amplitude on the left and right tuber coxae, right tuber coxae movement will show increased vertical movement during left hind stance, left tuber coxae during right hind stance. In a lame horse this then leads to increased movement amplitude on the side of the lame hindlimb as a consequence of the increased force produced and hence increased vertical pelvic acceleration and displacement during the contralateral sound hindlimb stance phase. The increased movement amplitude during sound hindlimb stance is then exacerbated on the contralateral (lame side) by means of pelvic rotation [13].



Technical systems that measure vertical motion asymmetries

There are two main types of technical devices that can be used to measure VMAs.

1. Inertial Measurement Units (IMUs)
2. Optical systems that use cameras

There are pros and cons of all these systems including aspects of practicality, time consumption, in what conditions they can perform, what they measure and how they are validated for clinical use.

The figure displays motion analysis systems that output vertical motion asymmetries. The four to the left are IMU systems and the two to the right use optical technology (one or several cameras).

	EQUINOSIS	Sleip	QUALISYS	EQUIGAIT	Equi PRO
Technology	Sensors	iPhone video	Optical motion capture - markers	Sensors	Sensors
Runs on	Windows tablet	iPhone	Windows	Windows/Phone	Laptop
Pros	-User friendly -Fail safe -(Withers)	-Synced video -User friendly -Very portable -Low cost -No marker/sensor attachment	-Most accurate, gold standard for validating the other systems. -Speed measuremet -Synced video -Withers	-Withers -Back measurements	-Long distance measures of for example trotters in harness possible -Limb measurements -Speed -Withers
Cons	-Limited range (Bluetooth)	-Fast internet needed -Hindlimb measurement in one direction only -Low resolution scale	-High cost -Fixed setup	-Needs syncing	-Needs syncing -Limb sensors

Pros and cons of the systems used by the research group at SLU.

Compensatory lameness mechanisms

The lameness evaluation is complicated by the occurrence of "compensatory movements", the horse tries to unload a painful limb, affecting the symmetry of the opposite half (front or hind quarters) of the body from the primary lameness [2,5-6, 14-15]. These compensatory mechanisms are also present during lungeing [16]. In horses with primary hindlimb lameness an ipsilateral compensatory forelimb lameness can be seen and such compensatory movements may contribute to inter-observer variability in lameness evaluation performed by veterinarians. Discrimination between circle dependent asymmetries, compensatory movement-, and pain-related asymmetries is therefore a prerequisite for successful evidence-based lameness assessment.

1. Fredricson, I., Drevemo, S., Moen, K., Dandanell, R., & Andersson, B: Equine Joint Kinematics and Co-Ordination. Acta vet. scand. 1972, Suppl. 37, 1-133.
2. Buchner, H. H., Savelberg, H. H., Schamhardt, H. C., & Barneveld, a. (1996). Head and trunk movement adaptations in horses with experimentally induced fore- or hindlimb lameness. *Equine Veterinary Journal*, *28*, 71–76. https://doi.org/10.1111/j.2042-3306.1995.tb04911.x
3. Keegan, K. G., Kramer, J., Yonezawa, Y., Maki, H., Frank Pai, P., Dent, E. v., Kellerman, T. E., Wilson, D. A., & Reed, S. K. (2011). Assessment of repeatability of a wireless, inertial sensor-based lameness evaluation system for horses. American Journal of Veterinary Research, 72(9), 1156–1163. https://doi.org/10.2460/ajvr.72.9.1156
4. Weishaupt, M. A., Wiestner, T., Hogg, H. P., Jordan, P., & Auer, J. A. (2006). Compensatory load redistribution of horses with induced weight-bearing forelimb lameness trotting on a treadmill. Veterinary Journal, 171(1), 135–146. https://doi.org/10.1016/j.tvjl.2004.09.004
5. Maliye, S., Voute, L., Lund, D., & Marshall, J. F. (2013). An inertial sensor-based system can objectively assess diagnostic anaesthesia of the equine foot. Equine Veterinary Journal, 45(S45), 26–30. https://doi.org/10.1111/evj.12158
6. Persson-Sjodin, E., Hernlund, E., Pfau, T., Andersen, P. H., Forsström, K. H., Byström, A., Serra Bragança, F. M., Hardeman, A., Greve, L., Egenvall, A., & Rhodin, M. (2023). Withers vertical movement symmetry is useful for locating the primary lame limb in naturally occurring lameness. Equine Veterinary Journal. https://doi.org/10.1111/evj.13947
7. Reed, S. K., Kramer, J., Thombs, L., Pitts, J. B., Wilson, D. A., & Keegan, K. G. (2020). Comparison of results for body-mounted inertial sensor assessment with final lameness determination in 1,224 equids. Journal of the American Veterinary Medical Association, 256(5), 590–599. https://doi.org/10.2460/javma.256.5.590

8. Mccracken, M. J., Kramer, J., Keegan, K. G., Lopes, M., Wilson, D. A., Reed, S. K., Lacarrubba, A., & Rasch, M. (2012). Comparison of an inertial sensor system of lameness quantification with subjective lameness evaluation. Equine Veterinary Journal, 44(6), 652–656. https://doi.org/10.1111/j.2042-3306.2012.00571.x
9. Hammarberg M, Egenvall A, Pfau T, Rhodin M. Rater agreement of visual lameness assessment in horses during lungeing. Equine Vet J. 2016;48(1):78–82.
10. Keegan KG, Dent E V, Wilson DA, Janicek J, Kramer J, Lacarrubba A, et al. Repeatability of subjective evaluation of lameness in horses. Equine Vet J. 2010;42:92–7.
11. Bell RP, Reed SK, Schoonover MJ, Whitfield CT, Yonezawa Y, Maki H, et al. Associations of force plate and body-mounted inertial sensor measurements for identification of hind limb lameness in horses. Am J Vet Res. 2016;77(4):337–45.
12. Starke SD, Raistrick KJ, May SA, Pfau T. The effect of trotting speed on the evaluation of subtle lameness in horses. Vet J. 2013;197:245–52
13. Pfau T, Fiske-Jackson A, Rhodin M. Quantitative assessment of gait parameters in horses: Useful for aiding clinical decision making? Equine Vet Educ. 2015;28:209–15.
14. Kelmer G, Keegan KG, Kramer J, Wilson DA, Pai FP, Singh P. Computer-assisted kinematic evaluation on a treadmill. 2005;66(4).
15. Maliye S, Marshall JF. Objective assessment of the compensatory effect of clinical hind limb lameness in horses: 37 cases (2011–2014). J Am Vet Med Assoc. 2016;249(8):940–4.
16. Rhodin M, Pfau T, Roepstorff L, Egenvall A. Effect of lungeing on head and pelvic movement asymmetry in horses with induced lameness. Veterinary Journal. 2013.

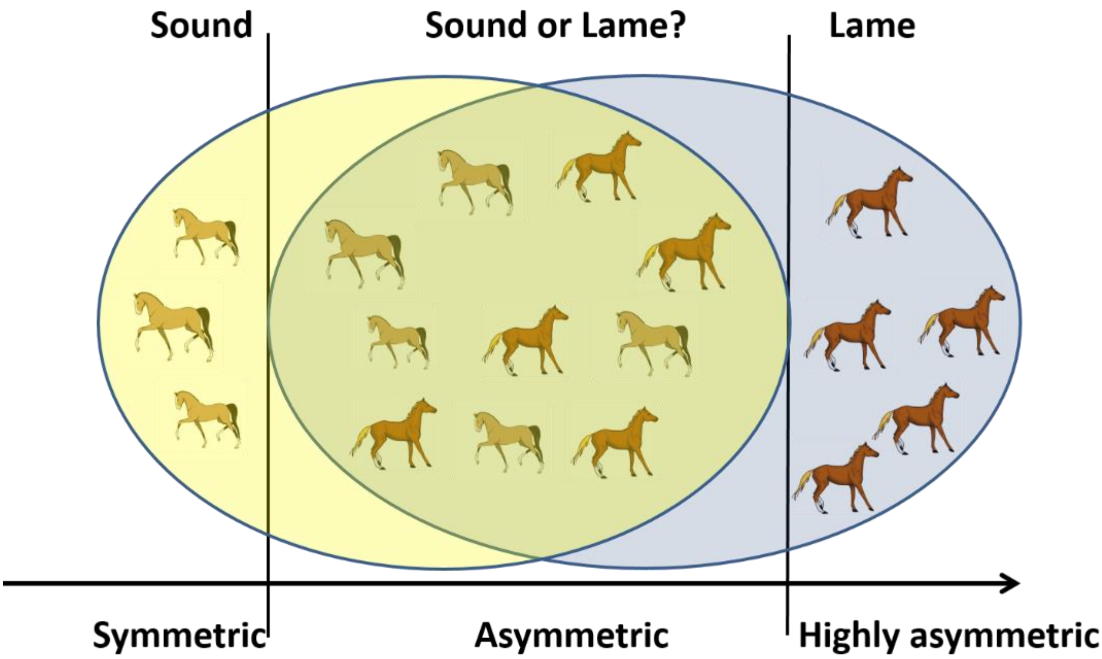
Normal variation of gait asymmetries. Asymmetry, laterality and lameness -what is what?

Vertical motion asymmetry, laterality, or anatomical asymmetry?

In a study of 222 riding horses in training, perceived as free from lameness by their rider, a remarkably high number, 161 (73%), of the horses showed motion asymmetries [1] and many reached the asymmetry threshold used for decisions regarding treatment of horses in clinical practice. Of the 161 horses with motion asymmetries 90 horses showed concurrent forelimb and hind limb asymmetries on the straight but we don´t know the prevalence of compensatory movement asymmetries .

Also when veterinary assessments are done of horses in full training that are perceived as sound by their owners undetected lameness is commonly found [2, 3]. At the same time, riding horses with elevated vertical motion asymmetries (VMAs) have been found unresponsive to meloxicam treatment at the group level [4]. This finding raises questions about whether inflammatory pain is responsible for the highly prevalent elevated VMAs. Anatomical asymmetry, such as limb length differences, affects VMAs [5], but it is an unlikely explanation for the full proportion of horses with elevated VMAs, as a substantial limb length difference is required to produce the asymmetry levels observed. Could the neuro-motor system be responsible for the asymmetry? Neuro-motor preferences, where one side is dominant, are often referred to as "motor laterality" or "sidedness" and can occur on an individual or population level. Laterality has been observed in several species, including horses, but the biomechanics of laterality are not yet fully understood.

Motor laterality in horses has been assessed using various methods [6]. These methods include observing the preferred forelimb during foraging, either on pastures or through standardized tests, and documenting the preferred limb for initiating movement and truck loading. Other indicators of laterality include the preferred lead during flat racing, the favoured side for turning to avoid obstacles, the side favoured for rolling, and the lateral displacement of the hindquarters when standing or trotting in a circle. Riders and experimenters have also evaluated laterality using judges' scores from competitions. However, other methods for assessing laterality during riding have rarely been compared, and agreement between different studies has been limited.



We see a large number of horses with motion asymmetries, but yet we do not know which of these horses are in pain and lame?

VMAs and their explanation beyond laterality

VMAs are not yet well explained by laterality. Recent studies have explicitly tested associations between VMAs and rider-perceived sidedness, as well as preference tests in elite competing and young warmblood horses [7, 8], but no strong associations have been found. Hence, the current state of knowledge does not support the idea that vertical motion asymmetry is explained by laterality or that VMAs are good measures of laterality. Instead, a recent publication indicates that more advanced biomechanical analysis of horses navigating turns can provide an interesting locomotor profile associated with rider-perceived laterality [9]. However, the potential role of musculoskeletal pain influencing the results cannot be ignored. The clinical relevance of VMAs needs to be interpreted in the context of thorough clinical assessment, functional performance assessment, and behavioural analysis of the horse.

References

1. Rhodin M, Egenvall A, Andersen PH, Pfau T. Head and pelvic movement asymmetries at trot in riding horses in training and perceived as free from lameness by the owner. PLoS One. 2017;12(4):1–16. https://doi.org/10.1371/journal.pone.0176253
2. Dyson, S., & Greve, L. (2016). Subjective Gait Assessment of 57 Sports Horses in Normal Work: A Comparison of the Response to Flexion Tests, Movement in Hand, on the Lunge, and Ridden. Journal of Equine Veterinary Science, 38. https://doi.org/10.1016/j.jevs.2015.12.012
3. Greve, L., & Dyson, S. J. (2014). The interrelationship of lameness, saddle slip and back shape in the general sports horse population. Equine Veterinary Journal, 46(6), 687–694. https://doi.org/10.1111/evj.12222
4. Persson-Sjodin, E., Hernlund, E., Pfau, T., Andersen, P. H., Forsström, K. H., & Rhodin, M. (2019). Effect of meloxicam treatment on movement asymmetry in riding horses in training. *PLoS ONE*, *14*(8), e0221117. https://doi.org/10.1371/journal.pone.0221117
5. Vertz, J., Deblanc, D., Rhodin, M., & Pfau, T. (2018). Effect of a unilateral hind limb orthotic lift on upper body movement symmetry in the trotting horse. PLoS ONE, 13(6), 1–14. https://doi.org/10.1371/journal.pone.0199447
6. Kuhnke, S., & König von Borstel, U. (2022). A comparison of different established and novel methods to determine horses' laterality and their relation to rein tension. *Frontiers in Veterinary Science*, *9*, 01–17. https://doi.org/10.3389/fvets.2022.789260

7. Leclercq, A., Lundblad, J., Persson-Sjodin, E., Ask, K., Zetterberg, E., Hernlund, E., Andersen, P. H., & Rhodin, M. (2023). Perceived sidedness and correlation to vertical movement asymmetries in young warmblood horses. PLoS ONE, 18(7 July). https://doi.org/10.1371/journal.pone.0288043
8. Zetterberg, E., Persson-Sjodin, E., Lundblad, J., Hernlund, E., & Rhodin, M. (2024). Prevalence of movement asymmetries in high-performing riding horses perceived as free from lameness and riders' perception of horse sidedness. *PLOS ONE*, *19*(7), e0308061. https://doi.org/10.1371/journal.pone.0308061
9. Egenvall, A., Clayton, H. M., & Byström, A. (2023). Pilot study of locomotor asymmetry in horses walking in circles with and without a rider. *PeerJ*, *11*, e16373. https://doi.org/10.7717/peerj.16373

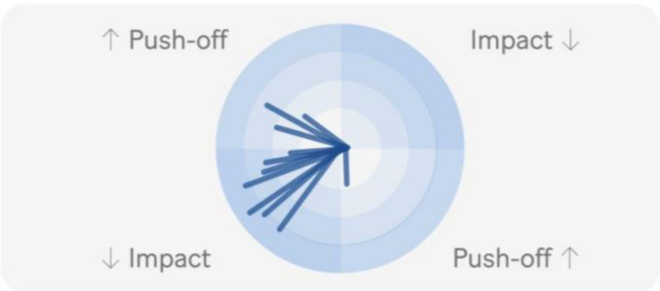
Gait variability and longitudinal gait monitoring. Can variation be a sign of neurological disease?

As a key component of the clinical assessment of lameness, Vertical Motion Asymmetry (VMA) measurements reveal detailed asymmetries in limb loading between forelimb and hindlimb pairs. Given the sensitivity of the measurement systems and the level of detail obtained some questions arise: When is an asymmetry clinically relevant? How do VMA measurements vary within and between days, or over longer periods? What information can be gleaned from stride-to-stride or measurement-to-measurement variation?

Inter-stride and inter-run variability

First, horses exhibit substantial stride-to-stride variability in VMA at the trot. Therefore, each measurement should be evaluated in terms of both the number of strides observed and the consistency of asymmetry between strides. Clinically, this stride-to-stride consistency is often as important as the magnitude of the mean asymmetry. A more consistent asymmetry typically warrants greater clinical attention.

In a 2011 study, Keegan et al. [1] assessed the repeatability of VMA measurements (using the Equinosis IMU system) within and between runs. Over 200 horses were trotted on a straight line, with each horse's measurement repeated after five minutes. The observed between-run variation, attributed to biological gait variability rather than technical factors, now informs the clinical thresholds used with this specific IMU system. The authors also recommended a minimum of 20 strides for reliable clinical assessment.



These are results from an asymmetry measurement. Each line represents the asymmetry recorded in one stride. The line is a vector displaying the Impact and Push-off asymmetry along two diagonal axes.

The consistency of the measurement is shown by the spread of the asymmetry vectors. The “broom stick” pattern is a consistent asymmetry repeatably observed from stride to stride, while the “star” pattern below displays low consistency.

Hardeman et al. [2] investigated inter-run variability in movement symmetry in 12 sound European warmbloods over two consecutive days (five runs per day) and reported substantial variation between runs. However, this variability may be lower in lame horses. Peham et al. [3] observed reduced stride variability in the presence of orthopaedic pain. The relationship between lameness severity and inter-run variability for specific parameters (HDmin, HDmax, PDmin, PDmax) requires further investigation.

In clinical practice, minimising the influence of inter-run VMA variability on lameness assessment is crucial. Professor Keegan strongly recommends stabilising lameness before sequential measurements are taken.

While consistent gait asymmetry is a key indicator of lameness, gait variability—or unexpected motion—can reveal insights into coordination. Assessing coordination is crucial in diagnosing proprioceptive ataxia in horses. However, few studies have identified motion descriptors suitable for detecting neurological disease. Notably, maximum vertical displacement of the distal limbs (pelvic and thoracic) demonstrated promising diagnostic potential in a 2017 study by Olsen et al. [4]. Research projects on the topic are currently ongoing.

Measurements of VMA over time

At the University Animal Hospital in Uppsala, we find longitudinal VMA data invaluable for orthopaedic case management. Serial measurements aid in monitoring rehabilitation progress and provide a valuable historical record when horses present with new lameness complaints. Our research group is conducting longitudinal studies of motion asymmetry in young riding horses, young trotters, and mature riding horses. We have observed that many horses exhibit a consistent, individualised VMA pattern ("fingerprint"). We are particularly interested in how these asymmetry patterns respond to training load and other management factors.

Few studies of longitudinal monitoring are yet published. Pfau et al. [5] found small but significant changes in movement symmetry in 23 sound cavalry horses across four shoeing stages (old shoes, no shoes, trimmed, and new shoes). Longitudinal studies on upper body movement symmetry during training are needed to compare sound and lame horses.

Each horizontal line of circles represents one measurement of vertical motion asymmetry performed in one day. Only measurements from the left lunge are filtered out. The different coloured circles represent impact or push-off asymmetry from fore- or hindlimbs. During the months of April and May this horse displays outer fore impact asymmetry.

1. Keegan, K. G., Kramer, J., Yonezawa, Y., Maki, H., Frank Pai, P., Dent, E. v., Kellerman, T. E., Wilson, D. A., & Reed, S. K. (2011). Assessment of repeatability of a wireless, inertial sensor-based lameness evaluation system for horses. American Journal of Veterinary Research, 72(9), 1156–1163. https://doi.org/10.2460/ajvr.72.9.1156
2. Hardeman AM, Serra Bragança FM, Swagemakers JH, van Weeren PR, Roepstorff L. Variation in gait parameters used for objective lameness assessment in sound horses at the trot on the straight line and the lunge. Equine Vet J. Published online 2019. doi:10.1111/evj.13075
3. Peham C, Licka T, Girtler D, Scheidl M. The Influence of Lameness on Equine Stride Length Consistency. Vet J. 2001;162(2):153-157. doi:10.1053/ tvjl.2001.0593
4. Olsen, E., FouchÉ, N., Jordan, H., Pfau, T., & Piercy, R. J. (2018). Kinematic discrimination of ataxia in horses is facilitated by blindfolding. Equine Veterinary Journal, 50(2), 166–171. https://doi.org/10.1111/EVJ.12737
5. Pfau T, Daly K, Davison J, Bould A, Housby N, Weller R. Changes in movement symmetry over the stages of the shoeing process in military working horses. *Vet Rec*. Published online 2016. doi:10.1136/vr.103516

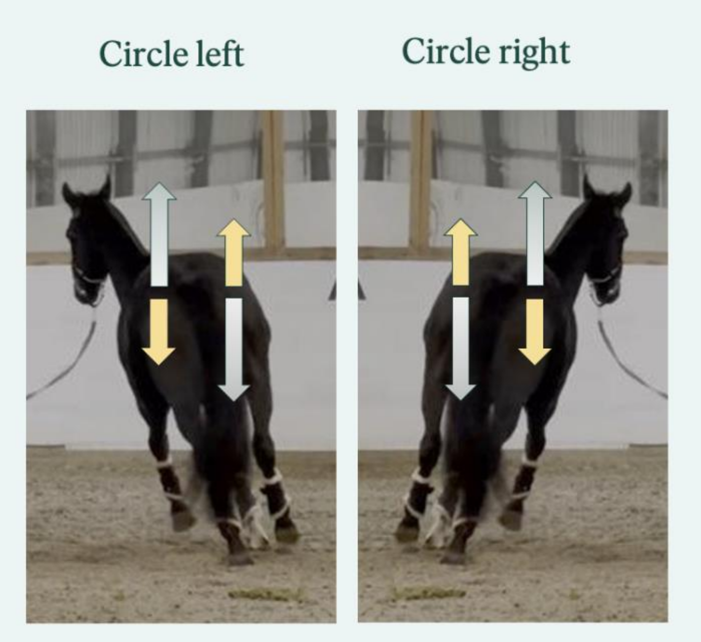
Lameness assessment during lungeing and the effect of the rider

Lungeing is commonly used during lameness and pre-purchase evaluations as it can amplify the degree of apparent lameness compared to a straight line trot. However, visual assessment of lameness while horses are trotting on a circle is difficult, as shown by the low inter-rater agreement among veterinarians evaluating lameness from videos of horses on the circle [1].

Certain patterns of movement asymmetry are recognized as normal during lungeing, based on studies of horses with symmetrical movement during straight-line assessments [2]. However, distinguishing these circle-induced asymmetries in sound horses from asymmetries caused by pain in lame horses is challenging, and this difficulty could partly explain the low inter-rater agreement. In the study comparing the agreement of visual lameness evaluations of horses during lungeing, the inter-rater agreement was lowest for classifying the horse as sound, with a kappa value of 0.08, where 1.0 signifies total agreement) [1].

Currently, there are no definitive thresholds to distinguish normal circle-induced asymmetries from asymmetries seen in bilaterally lame horses, but the lamest limb is often visible during a straight line trot.

Common asymmetric patterns observed in the pelvis include less upward movement during the push-off of the outside hindlimb (outer push-off asymmetry) and less downward movement of the pelvis during the impact of the inside hindlimb, giving the impression of inner hind limb impact lameness. Asymmetric patterns in one lunge direction were frequently not mirrored in the opposite direction (59% for the head and 54% for pelvis) [2]. Further research is needed to understand when the differences between directions signify pain and pathology and when it reflects biological variation as sidedness. The asymmetries caused by the circular movement can be affected by speed and circle radius. Therefore clinicians should aim to standardize speed and circle radius when evaluating horses on the lunge before and after diagnostic analgesia [3].



Most common circle induced pelvic asymmetries are an inner impact (PDmin) and outer push-off (PDmax) asymmetry.

When lungeing horses with symmetrical movement on the straight, the symmetry of their movement doesn't appear to be influenced by the surface. However, a hard surface can amplify forelimb-related asymmetries, particularly when the presumed affected forelimb is on the inside of the circle [4]. More research is needed to determine how the surface affects horses with different pathologies.

In a study on induced lameness (sole pressure), a hindlimb impact lameness (PDmin) was most pronounced when the lame hindlimb was to the inside of the circle. Conversely, forelimb impact lameness (HDmin) was most pronounced with the lame forelimb to the outside of the circle [5]. The primary hind limb lameness induced a compensatory head movement, which mimicked an ipsilateral forelimb lameness of almost equal magnitude to the primary hind limb lameness [5]. This could contribute to the difficulty in correctly detecting hindlimb lameness. Further research on compensatory patterns in clinical cases is needed to fully understand the lameness adaptation strategies on the circle.

Furthermore, in a group of horses with motion asymmetries (HDmin and PDmin) of unknown origin, the asymmetry was highest when the affected hindlimb was to the inside of the circle and when the affected forelimb was to the outside of the circle [6]. Further research on clinical cases with known diagnoses, whether the severity of lameness increases or decreases with the lame limb to the inside or outside of the circle, is warranted. This information could provide additional insights in locating the painful stimulus, thereby aiding in the decision-making process on where to start blocking.

The effect of the rider

Rising trot induces asymmetric vertical movement that mimics low-grade hindlimb lameness. The most prominent effect of the rising trot is a decreased upward movement of the hind quarters (decreased pelvic rise) likely related to the downward momentum acting on the horse when the rider actively rises, counteracting the push off movement of the hind limb aiming to propel the horse's hind quarters into the air. This decreased pelvic rise measurable during rising trot mimics a type of lameness termed 'push off lameness'.

When ridden on a circle, the asymmetry created by the asymmetrical movement of the rider rising 'on the correct diagonal' counteracts the horse's movement asymmetries caused by the circular path, hence rendering the horse's movements more symmetrical. This offers an explanation to the equestrian principle of rising on the 'correct diagonal' likely making the underlying more symmetrical movement of the horse more comfortable for the rider.

In horses with pre-existing lameness a push off type hindlimb lameness would be expected to increase when the rider moves downward into the saddle during the stance phase of the lame hind limb. An impact type hindlimb lameness on the other hand would be expected to decrease. When ridden on a circle the combination of asymmetry induced by rising trot, as well as the circular track can attenuate or reduce the horse's baseline asymmetry, depending on the sitting diagonal and direction on the circle. Understanding these effects is important for riders and trainers as well as veterinarians performing lameness examinations and other professionals evaluating ridden horses.

1. Hammarberg M, Egenvall A, Pfau T, Rhodin M. Rater agreement of visual lameness assessment in horses during lungeing. Equine Vet J. 2016;48(1):78–82. https://beva.onlinelibrary.wiley.com/doi/full/10.1111/evj.12385

2. Rhodin M., Roepstorff L., French A., Keegan K., Pfau T. Egenvall A. (2016) Head and pelvic movement asymmetry during lungeing in horses with symmetrical movement on the straight. Equine Veterinary journal, 48(3):315-20. https://pubmed.ncbi.nlm.nih.gov/25808700/
3. Pfau, T., Stubbs, N.C., Kaiser, L.J., Brown, L.E. and Clayton, H.M. (2012) Effect of trotting speed and circle radius on movement symmetry in horses during lunging on a soft surface. Am. J. Vet. Res. 73, 1890-1899. https://pubmed.ncbi.nlm.nih.gov/23176414/
4. Pfau T., Jennings,C., Mitchell H., Olsen E., Walker A., Egenvall A., Tröster S., Weller R., Rhodin M. (2016) Lungeing on hard and soft surfaces: Movement symmetry of trotting horses considered sound by their owners. Equine Vet. J. Jan;48(1):83-9. https://pubmed.ncbi.nlm.nih.gov/25297461/
5. Rhodin M, Pfau T, Roepstorff L, Egenvall A.(2013). Effect of lungeing on head and pelvic movement asymmetry in horses with induced lameness. Vet J. . 2013 Dec;198 Suppl 1:e39-45. https://pubmed.ncbi.nlm.nih.gov/24140227/
6. Rhodin M, Egenvall A, Andersen PH, Pfau T. Head and pelvic movement asymmetries at trot in riding horses in training and perceived as free from lameness by the owner. PLoS One. 2017;12(4):1–16. https://doi.org/10.1371/journal.pone.0176253