Movement asymmetries in lame horses at the walk and their correlation to lameness in trot

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Independent Project • 30 credits
Swedish University of Agricultural Sciences, SLU
Faculty of Veterinary Medicine and Animal Science
Veterinary Medicine Programme

Uppsala 2023

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Credits:	30 credits
Level:	Second cycle, A2E
Course Title:	Independent Project in Veterinary Medicine
Course code:	EX1003
Programme/education:	Veterinary Medicine Programme
Course coordinating dept:	Department of Clinical Sciences
Place of publication:	Uppsala
Year of publication:	2023
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Keywords:	Lameness, movement asymmetry, gait, walk

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Abstract

Most research concerning lameness examination methods are based on the gait trot. The walk has similar symmetrical qualities that could make it appropriate for lameness assessment. As some patients, and potentially some pathologies could benefit from being examined at the walk, the purpose of this case study was to investigate if movement asymmetry variables of the head/poll, withers and pelvis, showed statistically significant differences between horses when lame and non-lame after positive diagnostic anaesthesia. Forty-seven equine patients were included in the study, all incoming to the Swedish University Animal Hospital Horse Clinic (UDS Hästklinik) for lameness examinations during which a diagnostic anaesthesia was preformed and had a positive result (i.e. the lameness was blocked). They were measured using a multi-camera marker-based motion capture system at the walk and trot before and after local anaesthesia.

The displacement values of the markers placed on the horses were extracted from the motion capture software and analysed through a paired, two-tailed t-test to evaluate any statistical significance. The horses were grouped as to whether they were forelimb or hindlimb lame in trot and all lamenesses were converted into right limb lameness based on their values in trot. For both the forelimb and hindlimb lame horses, a smaller group of horses showing more severe lameness in trot were analysed separately again to be compared to the full group of forelimb/hindlimb lame horses.

Statistical significance was found for the difference in height of the minima of the poll (MinDiff Poll) in the "full group" and the difference in height of the maxima of the pelvis (MaxDiff Pelvis) in the "severe lameness group" for forelimb lameness. This study found no statistical significance before and after diagnostic analgesia for hindlimb lameness.

This may be due to the low sample size or a large variation of the compensatory motion patterns associated to lameness at the walk.

Keywords: Lameness, movement asymmetry, gait, walk

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1. Introduction

Orthopaedic illnesses causing lameness are some of the most common causes of veterinary involvement and euthanasia in horses. Lameness is defined as a structural or functional abnormality in stance or movement. It can be seen in both walk and trot but trot is the gait commonly used for gait and lameness examinations. (Baxter 2011:72; Bowden et al. 2020; Pollard et al. 2020)

The main part of research on equine lameness detection and evaluation is focused on the gait assessment in trot but there may be conditions better evaluated in the walk as well as in patients where the higher limb impact of trotting is contraindicated which would make the possibility of lameness examinations in walk essential. (Serra Bragança et al. 2021)

As there is little research on the topic – particularly when evaluating hindlimb lameness and lameness in clinical patients – the purpose of this study was to examine changes in the movement asymmetry of head and pelvis during the walk, in horses before and after a successful diagnostic analgesia.

2. Literature Review

2.1 Normal pattern of movement

2.1.1 Stride phases

There are five phases of the stride. They are landing, loading, stance, break-over and swing.

Hoof landing

The landing is when the hoof makes initial contact with the ground. The hoof receives the initial impact from the collision with the ground which is a high-acceleration event. (Thomason & Peterson 2008; Baxter 2011:69–72) - See Figure 1.

Figure 1: Image of the moment of landing in walk (Author's image)

Loading

The loading phase is when vertical load is gradually placed on the limb as the horse's centre of gravity moves over the hoof. Now the fetlock extends, the digital flexor tendons elongate, and the heel of the hoof widens. (Thomason & Peterson 2008; Baxter 2011:69–72) - See Figure 2.

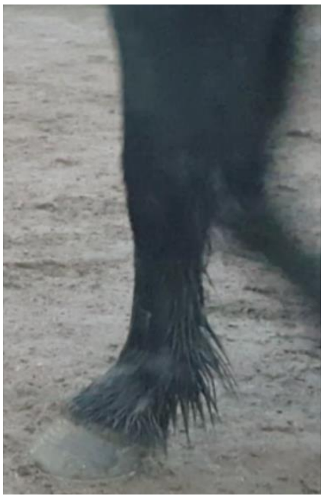

Figure 2: Image of the limb during the loading phase in the walk (Author's image)

Mid-stance

The mid-stance occurs when the peak vertical load is placed on the limb. After this moment of the stance phase, the vertical load decreases while propulsive forces are increasing. (Thomason & Peterson 2008; Baxter 2011:69–72) - See Figure 3.

Figure 3: Image of the limb during the stance phase in walk (Author's image)

Break-over

At the break-over, the leg leaves the ground. The heel of the hoof is lifted off the ground and the toe pivots. The break-over phase is defined as the time from when the heel of the hoof lifts off the ground until the toe lifts off the ground. (Thomason & Peterson 2008; Baxter 2011:69–72) - See Figure 4.

Figure 4: Image of the beginning of the break-over phase in a limb at the walk. (Author's image)

Swing

After the break-over phase, there is the swing phase when the limb travels in the air – first flexing and then extending to get ready for the landing phase. (Thomason & Peterson 2008; Baxter 2011:69–72) - See Figure 5.

Figure 5: Image of the end of the swing phase in a limb in the walk. (Author's image)

2.1.2 Walk

The walk is a four-beat, symmetrical gait which is unlike the trot, canter and gallop defined as a walking gait due to its lack of a suspension phase. The footfall sequence in the walk is as follows: left hind, left fore, right hind and lastly right fore. See Figure 6. There are multiple other gaits with the same footfall pattern seen in horses such as tölt, running walk and the characteristic gaits of the Paso Fino. They instead vary in the speed and timing of the footfalls as well as in the body posture of the horse. (Nicodemus & Clayton 2003; Clayton 2016)

Figure 6: Images of the footfall sequence in the walk. From the top left corner - left hind lands, left fore lands, right hind lands, right fore lands. (Author's images)

As opposed to trot, the walk has two different kinds of limb support phases – two-limb support and three-limb support. When the footfall of the left hind starts the stride cycle – both hindlimbs and the right forelimb are weight-bearing. This is then followed by left hind and right fore, left hind and both forelimbs, left hind and fore, both hindlimbs and the left fore, right hind and left fore, right hind and both forelimbs and finally the right hind and fore before the left hind becomes weight-bearing and the cycle restarts. This means the horse cycles between diagonal two-limb support, ipsilateral two-limb support and three-limb support consisting of either both hindlimbs and a forelimb or both forelimbs and a hindlimb. (Hildebrand 1965)

The walk is also defined as a stepping gait as it relies on the inverted pendulum mechanism to save energy. This means that instead of pushing off the ground like a spring, the horse's body rolls over the weight-bearing limb causing the potential energy to increase while the kinetic energy decreases and vice versa. (Clayton 2016)

A previous study has shown that the distribution of ground reaction forces of the limbs in the walk is highly contralaterally symmetrical and showed no statistically significant differences in magnitude between the fore and hind limbs. The pace of the walk did not alter the GRF. (Merkens & Schamhardt 1988)

2.1.3 Trot

The trot is a symmetrical, two-beat, running and leaping gait. The limbs move diagonally in the following pattern; right hind and left fore, suspension phase, left hind and right fore, suspension phase. As it is contralaterally symmetrical it is like the walk appropriate to use in lameness evaluations. The trot is defined as a running gait due to its suspension phases and as a leaping gait due to its use of the spring mechanism to conserve energy during push-off. (Clayton 2016)

2.2 Lameness

Lameness is an abnormal gait or stance due to functional or structural disorders. It is oftentimes caused by painful pathogenicities like trauma, infection, developmental disorders and vice versa but there are non-pain related, purely mechanical varieties. Several neurological pathologies also give the illusion of lameness when what is seen is ataxia. (Baxter 2011:72)

Lameness can be divided into either primary or compensatory lameness i.e., the lameness originates in a different limb and isn't a true pathology in the current leg. Compensatory lameness is usually seen on the ipsilateral forelimb when the primary lameness is in a hindlimb or on the diagonal hindlimb if the primary lameness is in a forelimb. (Uhlir et al. 1997)

This source claims that lameness is also classified as when it occurs in the stride. Impact lameness is seen when the load of the leg in question is reduced during the stance phase whereas push-off lameness occurs when the leg is pushing off before being lifted into the swing phase. Lameness can also be mixed and is then apparent in both phases. (Baxter 2011:65–66; Azevedo et al. 2015)

Horses alter the affected limb's load by changing the body's movement. This is seen as a decrease in the vertical movement of the head, withers, and croup during the stance phase while the opposite side shows an increase. The degree of abnormal movement increases with the severity of the lameness – making more subtle conditions more difficult to diagnose. (Buchner et al. 1996a; Baxter 2011:65–66)

Lameness can also affect the cranial i.e., the step length or the caudal step phase. The cranial phase is defined as the part of the stride where the leg is in front of the hoof print of the opposite limb whereas the caudal phase is when the leg is behind the hoof print of the opposite limb. This means that the cranial phase represents how much the leg is put forward while the caudal phase represents how far the horse has rolled over the leg i.e., how much the opposite leg is put forward. (Buchner et al. 1996a; Baxter 2011:65–66)

As stated in the following book, these phases can be affected by lameness in both shortening and lengthening. The changes in step length are best seen from a side view and abnormalities in the cranial phase are more easily seen than those of the caudal phase. (Baxter 2011:72)

The hindlegs are used to propel the body forward while the forelegs do proportionally more weight bearing. Foreleg lameness is the more common of the two. This differs between breeds and types of use, for example, dressage horses have a higher percentage of hindlimb suspensory ligament injuries than average. As the use of the horse is highly correlated with the type of lameness seen, it is an important factor to consider when examining. (Murray et al. 2006; Baxter 2011:75)

2.2.1 Forelimb lameness

Lameness located in the forelimbs is in general more easily detected by subjective methods than that of the hindlimbs at the trot. (Keegan et al. 2010; McCracken et al. 2012)

Head nods i.e., a lowering of the head during the stance phase of the sound limb is the most considerable sign of forelimb lameness. The same pattern is generally seen in the withers and croup but with a smaller magnitude. The head position is raised during the stance phase of the sound limb which moves the load towards it and may shift the weight of the body caudally. (Buchner et al. 1996a)

When trotted on a hard surface, the healthy foot will hit the ground harder thus making a louder sound. Shortening of the stride and swing durations, elongation of the stance phase of the sound limb and changes in inter-limb timing occur when there is a forelimb lameness and reduced hyperextension of the fetlock and reduced flexion of the coffin joint can be seen on the lame side. (Buchner et al. 1995b, 1996b; Baxter 2011:72–73)

In horses with bilateral problems, head movement abnormalities may be much more subtle than the pathology indicates as it does not want to increase the load on either leg. Some believe bilateral lameness may give the appearance of generally short and stiff strides in the forelimbs. (Buchner et al. 1995a; Baxter 2011:72–73)

Distal lameness is the most common in the forelimbs, though the type varies depending on the horse's discipline. Pain originating from the hoof, fetlock, carpus, and digital flexor tendons is often observed and distal origins should be excluded before proximal lameness is suspected. (Baxter 2011:75; Tank et al. 2020)

2.2.2 Hindlimb lameness

Hindlimb movement abnormalities are considered more difficult to evaluate than those of forelimbs. (Keegan et al. 2010; McCracken et al. 2012)

It has been shown that hindlimb lame horses show a higher amplitude motion of the tuber coxae and upwards than on the healthy leg during the swing phase. This is known as the hip hike. Many hindlimb lame horses will involve the gluteal muscles less and have a shortened stance phase on the lame side, which looks like the hip drops lower on the lame leg. (Kramer et al. 2004)

It has been shown that while the hip hike is an important subjective observation – many horses do not raise or lower the hip of the lame limb during push-off or stance respectively. The hip hike is believed to be a result of the movement of the healthy leg, not the lame one. (Kramer et al. 2004)

On the report of the below source, like the head nod, the hip hike's severity often corresponds to the severity of the lameness, making more subtle abnormalities more difficult to detect. (Baxter 2011:73–74)

Abnormal head movements can also be seen in connection with hindlimb lameness; however, it occurs during the stance phase of the sound limb as the displacement of the head decreases. According to the following study (Buchner et al. 1996a), the changes in the head movement have been seen to have a smaller magnitude during hindlimb lameness than during the forelimb variety and can be seen only in more severely lame horses. The level of displacement changes has also been seen to increase with the severity of the lameness. In cases of serious lameness, the head may be lowered and stretched. (Buchner et al. 1996a; Baxter 2011:73–74)

In the hindlimbs, lameness usually originates in the hock or stifle, but distal fractures and digital flexor tendon sheath problems are also moderately usual. (Baxter 2011:75; Tank et al. 2020)

2.2.3 Lameness in walk

The trot is the gait used to evaluate lameness in horses, thus lameness indicators in the walk have not been studied to the same extent. As certain lameness conditions are contraindicated with the increased impact load seen in trot, lameness evaluations in the walk would be a vital part of the examinations of these patients. Some believe the same goes for some movement abnormalities which could present more clearly in walk than the trot. (Serra Bragança et al. 2021)

A recent study has shown that the compensatory actions in the walk and trot differ, possibly making previous lameness research in the trot futile in evaluating lameness at the walk. The walk having both bipedal and tripedal weight-bearing phases, lower velocity, and a higher degree of lateral body movement than the trot could facilitate less visibly noticeable forms of compensation. (Serra Bragança et al. 2021)

Asymmetrical movement of the head and withers could be seen in forelimb lame horses in the walk although asymmetrical head motions also have been shown to be part of the normal variation of the pattern of movement in said gait. (Egenvall et al. 2020; Serra Bragança et al. 2021)

2.3 Lameness evaluation

When doing a lameness evaluation, the objectives are to find out if the horse is lame, how severe the lameness is, which leg or legs the horse is lame on and what is causing the lameness. This is to consider possible treatment options and to be able to give an accurate prognosis. (Baxter 2011:72)

The following source states that the anamnestic details are important in finding the lameness source. Signalment, duration and severity of the problem, previous medical history, use of the horse and activity before the injury may give clues as to what the diagnosis is. (Hildebrand 1965)

It also claims that the initial part of a lameness evaluation is usually a visual examination where the standing horse is observed from different angles. A general overview of the posture, conformation and body contour is taken before a more detailed visual examination looking for any asymmetries or abnormalities of hoof walls, musculature, synovial structures, tendons, bone structure and other soft tissues is done. Any weight shifting, leg conformation and asymmetries of the hooves are also noted. (Hildebrand 1965)

Once the visual examination is completed the entire horse is thoroughly palpated. More subtle abnormalities such as swelling, pain or warmth are detected this way and may give insight into possible origins of the lameness before the motion analysis. (Baxter 2011:83–85)

Once the horse has been examined at a standstill, it is viewed in motion. This is done to determine which leg or legs are involved and the severity of the lameness. This is done in a walk and trot on a straight line as well as on the lunge, with or without shoes, and at times the horse is ridden or driven to further investigate any asymmetries. (Baxter 2011:107–108)

Different kinds of manipulation take place when the initial lameness has been evaluated, usually in the form of flexion tests. The flexion test is a subjective method used to determine the agility, range of motion and the possible presence of pain in all or a set of joints in the limb. The severity of the lameness response correlates to the severity of the pathology in the limb. The leg is flexed for up to 60 seconds, after which the horse trots away, during which increased lameness on the flexed limb is considered a positive response. False positives are commonplace, especially in the distal forelimbs and in older horses, meaning all positive responses must be compared to the other clinical signs. (Busschers & Van Weeren 2001; Baxter 2011:108–110)

Flexion test results are dependent on the amount of force used; thus, it is important to standardise the process by using the same person for the bilateral flexions. Different people have different techniques; therefore, they could produce different responses when flexing the same area. (Keg et al. 1997)

To confirm the location of the pain, local anaesthesia is deposited either perineurally or into joints or other synovial structures. For perineural anaesthesia, the injection area is simply cleaned well with alcohol; for intrasynovial anaesthesia, the injections are done completely sterile. A pen or a similar object can be used to test whether the perineural nerve block has been effective to test skin sensibility. If the horse still has sensation in the supposedly blocked area, it will react to the stimulus. (Gough et al. 2002a; b; Baxter 2011:114–116, 124, 126)

To consider a response positive, the lameness should have decreased by at least 50% on the affected leg after the anaesthesia. Most anaesthesia will have had effect 30 minutes after injection. Intrasynovial anaesthesia is seen as generally more specific than a nerve block, but they also diffuse into nearby tissues and are less specific the longer the wait after injection. (Gough et al. 2002a; b; Baxter 2011:114–116, 124, 126)

2.3.1 Subjective lameness evaluation

Different methods of observation can be used to detect lameness when doing a subjective evaluation of a horse's movement. For forelimb lameness observing the presence of a head nod, tense shoulder or neck muscles, changes in height or movement of the distal limb during the swing phase, changes in step length, decreased or increased joint angles, asymmetrical side motions of the body and differences in sound between limbs are mentioned to be used for a lameness evaluation. For hindlimb lameness, these factors are hip hikes, an increase in the range of motion of the tuber coxae unilaterally, changes in the foot flight, abnormal head and neck movement, changes in stride length, unusual rise, or use of the gluteal muscles, decreased or increased joint angles and a tendency to drift away from one leg. (Baxter 2011:73–74)

It should be noted that the factors scientifically proven to correlate to lameness are mainly abnormal displacement patterns of the head, withers and pelvis. (Buchner et al. 1996a; Kramer et al. 2004)

Since hindlimb lameness often causes a complementary ipsilateral forelimb lameness, subjective evaluators tend to be misled into believing that the horse is primarily forelimb lame. The displacement of the withers can be measured to differentiate a true forelimb lameness from a complementary lameness. A hindlimb lame horse would have a contralateral asymmetry of the withers compared to the lame leg while a forelimb lame horse would show an asymmetry of the head and withers on the ipsilateral side. (Rhodin et al. 2018)

2.4 Objective lameness evaluation

There are multiple ways to study the motion of the horse's body. They can be divided into two main categories, kinetic and kinematic analysis. As defined by the following author: Kinetics is the study of the forces involved in prompting motion and concerns force, energy, work, acceleration, and velocity. Kinematics, on the other hand, is the study of position changes of a specified object during a specified time. Kinematics does not investigate the cause of motion and is, therefore, more easily and more often utilised when evaluating the body motion of the horse. (Barrey 2014:189–190)

2.4.1 Kinetic methods

Ground reaction force measuring

This method uses electronic force sensors to measure the force of the hoof during ground contact. These sensors can be placed on the floor as a force plate implement or directly onto the hoof as a shoe. This provides data on the vectors' sizes and directions and the exact location of the applied force. Force plates have high accuracy but are generally quite small with an active surface of only around $0.5m^2$. (Barrey 2014:192)

To measure the vertical ground reaction forces of all four limbs simultaneously, a treadmill-integrated force-measuring system can be used, however, there is at present only one of them in the world, at the University of Zürich. (Barrey 2014:192; Universität Zürich 2020)

The use of force-measuring shoes has thus far been a fairly common approach to studying the ground reaction forces during different kinds of movement. They are in general less accurate than the force plate variety and may alter the horse's movements as they oftentimes are heavy and add a significant amount of height compared to a regular shoe. (Barrey 2014:192)

2.4.2 Kinematic methods

Acceleration measurements

Acceleration measurements are done by attaching accelerometers to the horse's body which measure changes in velocity i.e., deceleration or acceleration. This signal is then sent to a computer for analysis. Using this method, even very small movements can be detected, and it can be used both for kinetic and kinematic studies. This is because the acceleration vector is proportional to the force impact on the horse's centre of gravity thus measuring the force used in the motion of the horse. For kinematic studies, the accelerometers' data could be used to calculate different stride variables or when placed on the hoof wall, the impact of different surface materials and shoes. (Barrey 2014:192)

This method is especially useful outside of clinic settings due to the easy setup but requires complicated calculations. (Barrey 2014:192)

High-speed chronophotography

Markers are placed on standardised anatomy points and the horse is filmed using high-speed cameras to track the locomotion. This produces a very large amount of data, and the processing is generally time-consuming as it oftentimes must be done manually or semi-automatically, however, new computerised systems are increasing the automatization.

When the number of cameras used is four or above, it is possible to receive a three-dimensional image of the horse. These systems are restricted by a limited field of view, although some systems use panning technology to combat this. These types of systems can be used to assess horses during their normal form of use e.g., jumping, dressage or racing.

Kinematic analyses produce data on the kinematic parameters, such as velocity, displacement, angle of rotation and many more but with additional information about the dimensions and mass distribution of the measured areas, kinetic parameters can be calculated. (Barrey 2014:190, 192)

Infrared marker-based motion capture

Infrared marker-based motion capture works by emitting infrared light which is then reflected by the reflective markers placed on the horse. The cameras then receive this as a two-dimensional image which is used by the linked computer system to calculate the exact coordinates of the markers. This information can then be processed using software and algorithms to show the horse's movement patterns and any presence of lameness. (Qualisys 2022; Nymoen n.d.)

It has been shown that infrared marker-based motion capture systems have a good level of accuracy compared to ground reaction force plates when evaluating lameness in horses and have the advantage of not being restricted as to where the hooves are placed. Thus, more strides can be analysed without requiring more than the original pieces of equipment or larger buildings. It does, however, rely on the accuracy of the algorithms used to predict the presence of lameness which likely improves the method's accuracy as better algorithms are developed. (Boye et al. 2014)

3. Materials and Methods

Forty-seven horses which came to the Equine Orthopaedics Clinic at the University Animal Hospital (UDS) at the Swedish University of Agricultural Sciences (SLU) as clinical patients booked for lameness examinations were used as the subjects of the study. Objective lameness evaluation data was collected from visits ranging from March 2016 to November 2022. The horses were measured in walk and trot in a straight line before and after positive diagnostic anaesthesia.

The horses ranged from ages 3-19 at the time of examination and were of the breeds Swedish Warmblood (SWB) (16), Scandinavian Coldblood Trotter (2), Warmblood Trotter (4), Dutch Warmblood (KWPN) (2), Danish Warmblood (2), Islandic Horse (2), Pura Raza Española (PRE) (1), Welsh Cob (1), Irish Cob (1), Lusitano (1) and Hanoverian Horse (2). There were also warmblood horses of unknown origin (3), mixed breed horses (3), mixed breed ponies (2) and horses of unknown breed (5). There were 21 mares, 18 geldings, 3 stallions and 5 horses of unknown sex.

The lameness was located to the right hind in 17 cases, the left hind in 11 cases, the right fore in 11 cases, the left fore in 7 cases and both the right and left fore in 1 case. The positive diagnostic anaesthesias were high 4-point (1), stifle joint (9), abaxial (11), TMT (tarsometatarsal) joint (1), fetlock joint (6), low 4-point (5), ringblock (2), digital distal palmar (3), infiltration suspensory ligament (5), coffin joint (3), digital flexor tendon sheath (1) and other (3).

Each horse was measured using an infrared marker-based system (Oqus 400, Qualisys AB, Motion Capture Systems, 411 05, Göteborg, Sweden). 9-11 reflective markers were placed on the horses, three on the head placed on the centre, left and right sides of the forehead respectively, three on the withers, one placed at the highest point of the thoracic vertebrae and two on the left and right sides respectively, one on the centre of the sacral tuberosity and the other two on each coxal tuberosity. Additionally, a reflective marker was placed on the poll for newer visits as well as a marker on the right carpus – this one was however not included in the algorithmic evaluations but used as an aid for the manual relabelling of mislabelled markers in the software.

The measurements were manually looked through, and incorrectly labelled markers were relabelled and then processed through a MATLAB script to produce overseeable values for the movement of the markers. The values were summarised by trial measurement from the raw data of values of each step and the MaxDiff, MinDiff, RUD and ROM (range of motion) means were used for the analysis. MaxDiff is the difference between the two maxima of the stride while MinDiff is the difference between the two minima of the stride. RUD is the range of upward motion between the contralateral halves of the stride. In trot, negative values indicate a left-sided asymmetry and thus lameness and positive values indicate a right-sided lameness. The measurements were converted to right-side lameness by multiplying the left-side lamenesses by -1. This was based on the values of the trot measurements.

The inclusion criteria for horses included in this study were that they were measured in walk and trot before and after positive diagnostic anaesthesia, they had a MinDiff and/or MaxDiff <-15mm or >15mm for the head/poll measurements or <-7mm or >7mm for the pelvis and/or a RUD of >20mm for the head/poll or >10mm for the pelvis in the trot, the variables indicating lameness improved by at least 70% post-anaesthesia and that the trot measurement used had at least 8 steps measured. There were no inclusion criteria for the number of steps analysed in the walk. For the hindlimb lame horses, the number of analysed steps in the walk was 11-31 with a mean of 18.25 steps. For the forelimb lame horses, the number of analysed steps was 4-23 with a mean of 17.47 steps where there was one measurement containing only 4 steps – excluding that measurement the range was 12-23 and the mean of the number of steps analysed was 17.82.

A paired, two-tailed t-test was conducted to determine the statistical significance between pre- and post-anaesthesia conditions. The fore- and hindlimb lameness measurements were analysed separately. The groups were analysed both with all measurements and in a selection of the lamest horses. The more severe lameness groups had the inclusion criteria of a higher absolute value than 50 (thus <-50mm or >50mm) in the MinDiff and/or MaxDiff for the forelimb lameness and 25 (<-25mm or >25mm) in the MinDiff and/or MaxDiff for the hindlimb lameness respectively. There were 9 horses in the Severe Lameness group for forelimb lameness and 11 horses in the Severe Lameness group for hindlimb lameness. The significance level was chosen to be 0.05.

Four horses were used twice in the analysis. Three of them had multiple visits that fit the inclusion criteria where the positive diagnostic anaesthesia was done in different areas during the different visits, and one was bilaterally forelimb lame where it presented left forelimb lame initially and right forelimb lame after the first diagnostic anaesthesia. Due to this, the first anaesthesia was placed in the left forelimb and the second in the right forelimb. For that horse, the measurements were analysed in two pairs – initial lameness vs first post-anaesthesia and first post-anaesthesia vs second post-anaesthesia.

4. Results

4.1 Forelimb lameness

For the full group, the difference in the MinDiff Poll was statistically significant; for the Severe Lameness group, the difference in the MaxDiff Pelvis was statistically significant. Neither of them was statistically significant in the other group with a wider spread of MinDiff-values in the Severe Lameness group than in the full group. For the MaxDiff Pelvis-values, the standard deviation is slightly higher in the full group compared to the Severe Lameness group and the difference in means is more than doubled in the Severe Lameness group compared to the full group. See Tables 1 and 2 as well as Figure 8.

The MinDiff Poll-value showed a negative value pre-anaesthesia and a positive value post-anaesthesia with a 16.05mm difference in means. The spread of the values and the standard deviation is lower in the post-anaesthesia group making the group more homogenous. See Figures 7 and 8.

The MaxDiff Pelvis-value in the Severe Lameness group showed a negative value pre-anaesthesia and a positive value post-anaesthesia with a 2.81 mm difference in means. In the full group, the difference in means was 1.23 mm. See Figure 9.

Table 1: Means (in millimetres), standard deviations and p-values of forelimb lameness measurements in all horses. 0.05 significance level

	Mean Pre-Anaesthesia	Standard Deviation	Mean Post-Anaesthesia	Standard Deviation	P-value
MinDiff Poll	-7.50	26.35	8.55	21.35	0.01
MinDiff Withers	-6.93	7.23	-3.99	9.83	0.32
MinDiff Pelvis	1.23	6.52	0.78	6.19	0.73
MaxDiff Poll	-5.16	14.55	-8.14	19.15	0.49
MaxDiff Withers	0.004	4.65	0.12	4.84	0.91
MaxDiff Pelvis	-1.06	2.94	0.17	3.13	0.16
RUD Poll	1.19	25.6	14.83	27.99	0.09
RUD Withers	6.08	9.30	4.35	8.68	0.50
RUD Pelvis	2.29	8.13	0.61	8.71	0.36
ROM Poll	127.23	20.28	121.29	23.20	0.11
ROM Withers	59.77	103.96	36.56	11.34	0.35
ROM Sacrum	70.87	13.39	71.02	14.21	0.93

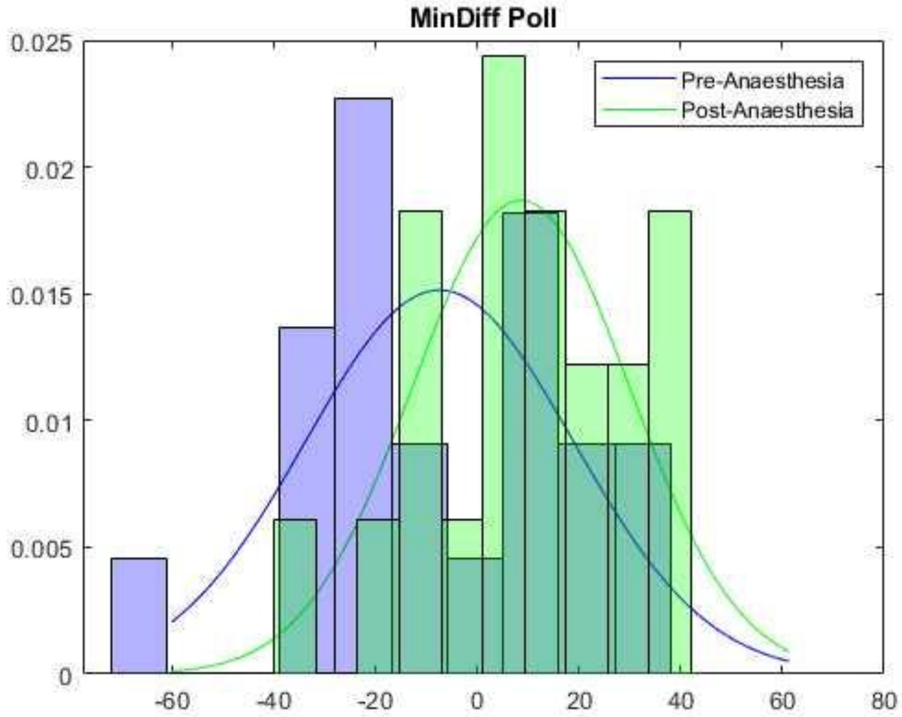

Figure 7: Normal distribution curves and histograms of the MinDiff Poll pre- and post-anaesthesia in the full forelimb lame group.

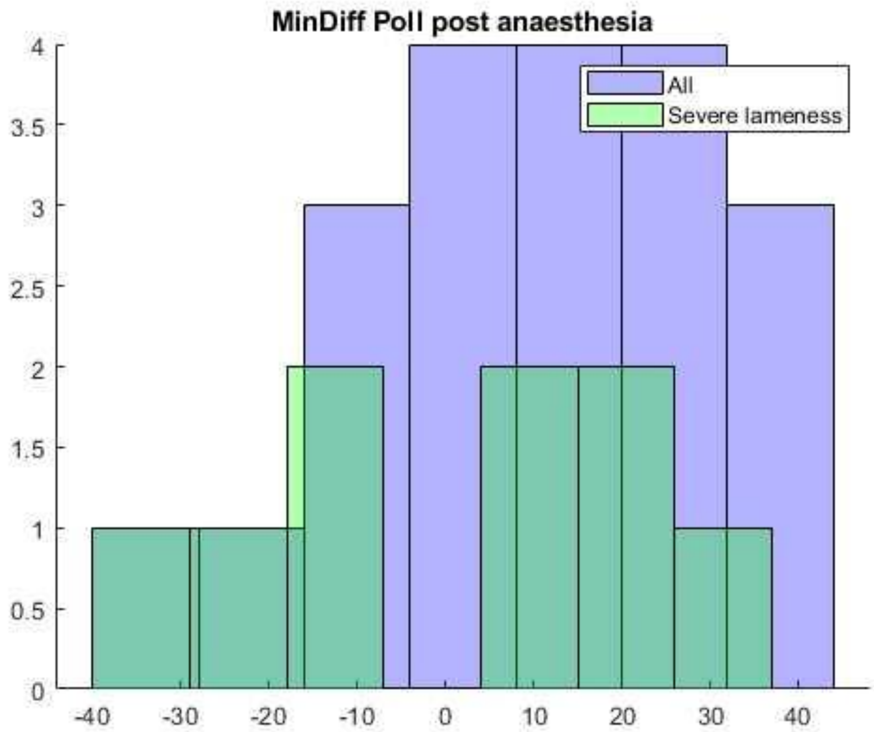

Figure 8: Histograms of the MinDiff Poll post-anaesthesia in the full group and the Severe forelimb Lameness group.

Table 1: Means (in millimetres), standard deviations and p-values of forelimb lameness measurements of the Severe Lameness group. 0.05 significance level

	Mean Pre-Anaesthesia	Standard Deviation	Mean Post-Anaesthesia	Standard Deviation	P-value
MinDiff Poll	-16.21	24.62	0.83	24.40	0.11
MinDiff Withers	-9.17	7.03	-0.41	9.86	0.13
MinDiff Pelvis	0.89	7.70	0.96	4.60	0.97
MaxDiff Poll	-6.68	17.22	-5.29	22.77	0.80
MaxDiff Withers	0.52	5.72	0.78	4.35	0.79
MaxDiff Pelvis	-1.70	2.37	1.11	2.68	0.01
RUD Poll	-9.52	28.16	6.12	22.27	0.20
RUD Withers	8.68	10.28	1.75	7.82	0.15
RUD Pelvis	2.59	8.52	-0.15	6.00	0.23
ROM Poll	131.45	26.52	126.54	21.41	0.21
ROM Withers	90.46	153.74	38.97	12.80	0.36
ROM Sacrum	69.67	16.20	71.26	16.07	0.62

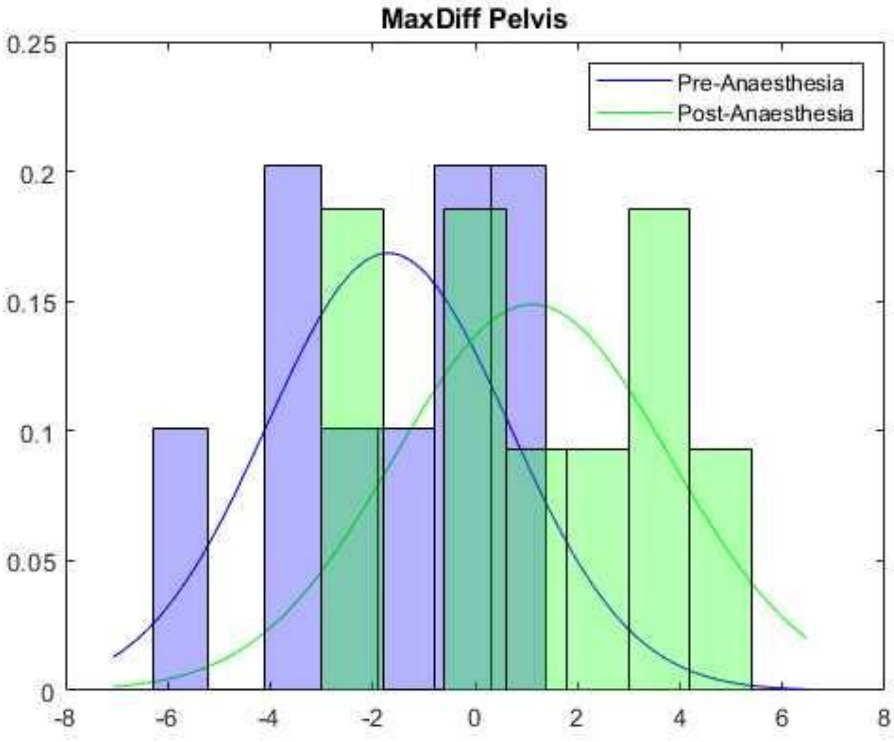

Figure 9: Normal distribution curves and histograms of the MaxDiff Pelvis pre- and post-anaesthesia in the Severe forelimb Lameness group.

4.2 Hindlimb lameness

There were no statistically significant differences for the variables in horses with hindlimb lameness. For most values, there is little difference between pre-and post-anaesthesia, however, for the MaxDiff Poll, MinDiff Poll and RUD Poll of the Severe Lameness group, the differences in means were 5.47mm, 8.15mm and 13.62mm respectively. The standard deviation was in general relatively high for all hindlimb parameters, and the spread was likely wide. See Tables 3 and 4.

Table 2: Means (in millimetres), standard deviation and p-values of all hindlimb lameness measurements. 0.05 significance level

	Mean Pre-Anaesthesia	Standard Deviation	Mean Post-Anaesthesia	Standard Deviation	P-value
MinDiff Poll	-4.88	19.69	-5.20	22.46	0.92
MinDiff Withers	1.66	12.18	-0.34	11.49	0.40
MinDiff Pelvis	-0.44	9.22	-0.67	8.43	0.86
MaxDiff Poll	2.89	10.92	4.93	15.01	0.44
MaxDiff Withers	0.80	9.55	1.41	9.96	0.52
MaxDiff Pelvis	1.06	3.80	1.24	3.90	0.82
RUD Poll	-7.77	25.51	-10.13	30.51	0.59
RUD Withers	0.70	17.69	-2.36	18.19	0.10
RUD Pelvis	-0.88	11.44	-2.04	8.97	0.51
ROM Poll	125.90	36.01	125.63	27.53	0.95
ROM Withers	37.50	9.62	39.68	11.36	0.14
ROM Sacrum	69.22	15.15	70.91	14.76	0.29

Table 3: Means (in millimetres), standard deviations and p-values of hindlimb lameness measurements of the Severe Lameness group. 0.05 significance level

	Mean Pre-Anaesthesia	Standard Deviation	Mean Post-Anaesthesia	Standard Deviation	P-value
MinDiff Poll	-2.94	27.19	-11.08	26.16	0.21
MinDiff Withers	-4.02	15.75	-1.36	15.34	0.39
MinDiff Pelvis	2.86	8.60	0.78	5.83	0.39
MaxDiff Poll	2.86	10.90	8.33	16.80	0.16
MaxDiff Withers	0.10	10.29	0.76	13.51	0.76
MaxDiff Pelvis	1.28	5.05	2.69	5.20	0.18
RUD Poll	-5.80	31.82	-19.42	34.99	0.09
RUD Withers	3.01	21.13	-0.88	24.43	0.36
RUD Pelvis	2.09	10.82	-1.64	5.72	0.18
ROM Poll	139.75	48.57	135.45	27.28	0.72
ROM Withers	38.51	12.92	40.73	12.23	0.20
ROM Sacrum	75.13	15.59	77.32	17.56	0.47

5. Discussion

Forelimb lameness

For the forelimb lameness, the only statistically significant values were the MinDiff Poll of the full group and the MaxDiff Pelvis for the Severe Lameness group. For the MinDiff Poll values it is interesting to note that they were no longer significant in the Severe Lameness group which means that there was no connection between a more obvious head nod and a more severe lameness as I had hypothesised.

Hindlimb lameness

The hindlimb lameness group did not show any significant values at all in this study which could be due to a small sample size, a too-low number of steps analysed in the measurements, breed variation, too-small asymmetries, a too-large time variation between the pre-and post-anaesthesia measurements in trot versus walk, large normal variation, or compensation by gait strategies that were not measured.

Ways of compensation

This result could mean that horses compensate in other ways with more severe lameness, that the head nod might not be a very sensitive or specific indication factor for lameness or that the natural variety in head movement asymmetries overlap greatly with the abnormal asymmetries. As can be seen in Figure 8, the values of the Severe Lameness seem more spread out than the values of the full group. This could indicate that more lame horses may find more ways to compensate for the lameness, but it could also indicate that the sample size was too small. These other kinds of compensation could be things the equipment used in this study could not pick up on with the set-up used, such as a longer three-limb support phase or a decrease in the extension of the fetlock joint on the affected limb.

As stated in the following article (Serra Bragança et al. 2021), stance and stride duration has been seen to shorten during forelimb lameness in the walk and fetlock extension, and protraction speed and maximum limb retraction angle have been seen to decrease. All these factors are things the set-up used might not pick up on as reflective markers were only placed along the topline of the horses (Serra Bragança et al. 2021).

In the Severe Lameness group, the MaxDiff Pelvis was statistically significant, and its mean also moved from the negatives into the positives. See Figure 9. This indicates that there was a decreased height of the pelvis during the midstance of the left hindleg when the horse was right foreleg lame. This could mean that the horse reduces the force placed on the sore foreleg by using less power in the push-off of the diagonal hindleg. In theory, this could be to decrease the forces from braking during the landing and loading phase of the front right leg. As the head and the pelvis move out of phase with the withers in the walk (Rhodin et al. 2022), it might also be a way to decrease the load of the lame right forelimb. This also coincides with the compensatory contralateral hindlimb lameness that can be seen in trot when the primary lameness is a forelimb lameness (Uhlir et al. 1997).

Gait kinematics

The mean of the MinDiff Poll moved into the positive after the anaesthesia. See Figure 7. The software used calculates the asymmetry between the two sides by subtracting the value of the first minima or maxima from the second minima or maxima in the stride cycle. The stride cycle is defined to start when the left hindlimb is placed on the ground, per the following article (Roepstorff et al. 2021).

The first minimum occurs when the hindlimbs are both weight-bearing and the left hind is further back, about to be lifted into the swing phase and the second minimum occurs when the opposite back-footing is seen. This coincides with the contralateral front hoof being in midstance. The first maximum is seen when the left hindlimb is in midstance and has rolled up to its peak during the pendulum motion and the second maximum is seen with the mirrored footing. This coincides with the three-limb support phase when the contralateral front hoof is about to be lifted into the swing phase. (Roepstorff et al. 2021)

This means that a negative MinDiff Poll indicates the head nod was lower during the loading phase of the right forelimb i.e., when the right forelimb was in the forward weight-bearing position, for a right forelimb lameness. This is opposite to trot lameness as the horse has a head nod on the non-lame side and raises its head when weight-bearing on the lame leg.

There is also the fact that the walk kinematically differs from the trot which could mean a lower sensitivity. According to the following article (Rhodin *et al*. 2022), due to the maxima being in the midstance of the hindlimbs, it is difficult to use that value to measure push-off lameness as opposed to in the trot where the maxima are seen during the moments of push off.

This in combination with it being a walking gait could potentially give horses more ways of compensating for pain but possibly also less pain as the load on the affected leg will be more gradual due to the double peak nature of the ground reaction force during the stride. The vertical ground reaction force is also generally higher in trot than in walk which could decrease the pain reaction in the walk. (Clayton & Hobbs 2019)

Sample population

This case-control study used clinically lame horses before and after successful diagnostic anaesthesia to utilize each case as their own control, thus, eliminating the influence of some variation in movement between individuals. While this has the advantage of enabling a smaller sample size and still achieving statistical significance, it poses the risk of a larger bias. This is because a smaller sample size poses a higher risk of not representing the entire population accurately.

The sample in this study may compensate in different ways than the population at large as the individual horses may use less common methods of compensation or the group at large has a larger or smaller variation in how they compensate. It is also possible that not only different anatomical locations, but different diagnoses may alter the pattern of movement in the walk – which is not a factor that has been added in this study. Anatomical confirmation in form of the breed but also skeletal and muscular conformation, natural asymmetry and past injuries could alter the pattern of movement during the lame walk – which not enough research has been conducted on to be certainly excluded or included as determining factors. The use of the horse is also not mentioned in this study, and it may also cause changes in asymmetry parameters during lameness in the walk.

It should also be noted that clinical patients vary in their degree of lameness in a way experimentally induced horses do not and as the horses in this study vary from 0.5-3 degrees of lameness at the trot when subjectively examined they may not be representing the average lameness grade of the population and it excludes more severely lame horses – as they are generally not evaluated in this way. It is also worth mentioning that the subjects in this study to a large part were not subjectively seen as lame in the walk. While there is not enough research on the topic to determine what factors to look at for lameness in the walk, there is also a possibility that at least some of this sample group was not lame in the walk which would have skewed the data.

Individual and group variation

It has, however, been shown that there are significant differences in the normal range of multiple kinematic factors between different breeds. Factors such as stride length and range of motion of the head vary depending on the breed making an interval describing the normal interval difficult (Rhodin et al. 2022). For a horse with a smaller range of motion of the head, a smaller change could be a sign of lameness as fewer millimetres represent the same percentage of variation.

Problems in the study

In this study, the number of analysed steps was not an inclusion criterion for the walk measurements. This could very likely give a flawed result and non-representative measurements and values. The time between diagnostic anaesthesia and the recording of the measurement post-anaesthesia is also a factor that has not been investigated in this study and in no way has been standardized. This means that there is no way of knowing how the time would affect a walk lameness and that too might be a reason for a large variety of values.

In this case, factors which could be checked for population prevalence such as the anatomical location of orthopaedic injuries or the distribution of breeds included could be misrepresenting the population but factors of which we do not have data yet could also be a cause for bias. It is for example reasonable to entertain the possibility that there might be a larger variation in how horses compensate for orthopaedic pain in the walk than in trot as there are both two- and three-limb support in the walk (Hildebrand 1965).

In this study, horses have been used multiple times in the analyses which causes a possible bias as that individual has double the effect on the statistics. Due to this, it is quite likely that the paired t-test was not the most appropriate statistical method for this study. The horses included are also clinical patients meaning that the study is not as standardized as an experimental study inducing lameness would be. These horses vary in anamnesis, age, gender, breed, use, diagnosis, size, and severity of lameness which in turn could cause large varieties in the data. The advantage is that they represent the entire population in a better way than a more homogenous experimental sample group. As clinical patients have been used, there is a higher chance of a more representative selection of clinical patients in the population.

However, it should be noted that these owners all have chosen an animal hospital for their lameness examinations and that many of the common patients would be seen in the field. An animal hospital visit may come with a higher expense, be more time-consuming and specialist competence. This might mean that the horse owners to a larger extent are willing to spend a larger amount of money and time on the horse at that point in time – which could imply a larger percentage of horses competing at higher levels, of horses with long-term problems, of horses with difficult to diagnose problems and of horses of certain uses and breeds.

In conclusion

In conclusion, horses are seen to show forelimb lameness in the walk with head nods as seen in trot, however the results carry some uncertainty since the more severely lame sub sample does not show this pattern. This may be due to multiple reasons ranging from factors based on the low number of study samples and a potential large variation in the asymmetry patterns at the walk. They show a diagonal compensatory hindlimb lameness in more severe forelimb lameness conditions, which might be directed to shift weight away from the lame limb at landing and loading. For hindlimb lameness, this study found no significant factors.

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Popular Science Summary

When veterinarians conduct lameness examinations, the trot is the gait commonly used for lameness location and evaluation, however, the walk is also suitable for this purpose and may be more suitable for horses that cannot or should not trot. There is, however, very little research done on the topic of lameness in walk and the purpose of this study is to investigate possible factors that can be used to locate lameness in the walk. This was done by filming horses with reflective markers placed on standardised points with infrared cameras to determine the locations and movements of the different points. The horses were filmed lame when first entering the orthopaedic clinic and after successful diagnostic anaesthesia of the painful structure.

A computer program then calculated values comparing the movement of the marker points and the values used in this study were the difference between the highest and lowest points during a stride, the upwards movement of the markers and the range of motion of the markers. The horses were selected based on their level of lameness seen in the values and then the improvement after diagnostic anaesthesia in the trot. Paired, two-tailed t-tests were performed to investigate the statistical significance between the lame and non-lame measurements. A smaller group of more lame horses were picked out and analysed separately to see if increased lameness showed any other results.

The results showed that the horses in the study had a head nod on the healthy leg when forelimb lame when the full group was analysed but not when the lamer horses were analysed separately. It also showed that the lamer horses had a diagonal push-off lameness in the hindleg of the painful limb. For hindlimb lameness, there was no statistical significance found.

These results may be because too few horses were analysed in the study, that horses' compensation methods in the walk have a larger variation than in the trot, that some of them were not actually lame in the walk or that they simply compensate in ways that were not measured in this study.

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