Gait screening using a mobile phone application

– Horse asymmetry levels and usability of a mobile phone application for gait analysis, during a long format FEI eventing competition

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Abstract

Orthopaedic disorders are the most common reason for unplanned rest in the performing horse population. Locomotor disorders which slowly build up to clear lameness might be avoidable with easy access objective motion measurement devices. An early detection of a disorder affecting the locomotor apparatus will lead to an early diagnosis and directed treatment to avoid chronic, irreversible damages to the tissues, often caused by long drawn inflammation.

During the last 30 years, biomechanical researchers have established and refined sensitive objective measures of lameness. Decreased loading of a painful front- or hind limb leads to a vertical motion asymmetry of the head or pelvis respectively at the trot. These asymmetries can be detected with high precision and accuracy, but the relevance of small amplitude asymmetries is not fully elucidated and clear thresholds for where an asymmetry is likely to reflect a painful condition are lacking.

Several studies have investigated the prevalence of motion asymmetries in different horse populations, revealing that asymmetries above clinically used thresholds are very common, ranging from 73-90% in mature riding horses, youngsters, endurance horses, standardbred trotters and polo horses. These high prevalence numbers and the sensitive measurement devices available have raised the question whether these asymmetries are caused by pain or if it is a question of biological variation of the gait pattern. In the search for the relevance of mild and moderate motion asymmetries, the relation to a high performing locomotor system is of particular interest. Therefore, studying horses that are judges to be “fit to compete” for high level events could provide insight.

The aim of this study was to describe vertical movement symmetry of head and pelvis in eventing horses as they trotted up during the horse inspection before and during an international FEI long format eventing competition. The asymmetry was described for horses that passed and did not pass the inspection. We investigated how the horses responded to the strenuous cross-country section of the competition by studying if the symmetry changed from the first to the second horse inspection (before and after cross country). In addition to the description of asymmetries on a group level, we also evaluated the usability of the mobile phone gait analysis tool, Sleip AI, which was used during the study.

In total, 58 horses were recorded using a computer vision tool for gait analysis at the horse inspections at one FEI long format eventing competition. At the first horse inspection, 36% of the horses showed asymmetry of mild type or more, on one leg or more. In spite of the high exercise load during the cross country, 52% of the 44 horses presented at the second horse inspection (after the cross country) improved their total asymmetry, 36% had a worsening/increased total asymmetry and 11% remained unchanged in their total asymmetry level. No significant difference on a population level was found (p =0.77) using a paired non-parametric test (Wilcoxon signed rank test), when looking at all the groups, first compared to the second horse inspection. The level of measured movement asymmetry using the gait analysis app was higher in the horses which were given a non-pass (sent to holding) compared to the ones that were subjectively judged to be fit to compete and were given a “pass”, but this was not statistically tested due to the low number of horses sent to holding. Horses that got a straight away “pass” at the first horse inspection (n =53) had a median asymmetry score of 0.95 for total asymmetry. The runs that generated a “holding” decision (n =5), had the median score of 2.1 for total asymmetry at the first horse inspection. At the second horse inspection the “pass” (n =42) had a median score of 1.05 and the “holding” (n =2) a median score of 1.75. Some horses with high degree of asymmetry slipped through the “pass”. Objective gait analysis can be useful in order to pick these horses out for a second control. We observed that many of the outliers with a high degree of asymmetry were white/grey-coloured horses. When looking at the total asymmetry and the outliers in the “pass”-group at the first and second horse inspection 3/5 and 3/3 horses were white coloured. This might indicate white horses are visually more difficult to assess. A mean of 11.8 trot strides were recorded for the front limbs during the first horse inspection and 7.4 trot strides for the hind limbs. During the second horse inspection a mean of 12.2 trot strides were measured for the front limbs and 8.5 for the hind limbs. In order to render a more reliable interpretation of the gait analysis, more trot steps should be recorded. This could be made possible if the trot up was longer.

To conclude, around one third of the eventers studied showed mild or more accentuated motion asymmetry at the day of the competition and surprisingly, the majority of this group of eventers improved their total motion asymmetry after the cross country. The mobile phone gait analysis application seemed to be a useful decision-tool for gait screening, but the horses should be trotted more strides in order to improve the reliability of the motion analysis.

Keywords: Gait analysis, Motion asymmetry, performing horses, FEI eventing, Artificial Intelligence, computer vision, kinematics, gait screening, mobile phone application

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Abbreviations

FEI	Fédération Equestre Internationale (The International equestrian federation)
HI1	Horse- inspection 1
HI2	Horse-inspection 2
HDmax	Head difference maximum
HDmin	Head difference minimum
PDmax	Pelvic difference maximum
PDmin	Pelvic difference minimum
OMDs	Objective motion measurement devices
SD-HDmax	Standard deviation head difference maximum
SD-PDmax	Standard deviation pelvic difference maximum
SD-HDmin	Standard deviation head difference minimum
SD-PDmin	Standard deviation pelvic difference minimum
SLU	Swedish University of Agricultural Sciences

1. Introduction

1.1. General introduction

Orthopaedic disorders are the most common reason for unplanned rest in the performing horse population (Penell *et al.* 2005). A locomotor disorder that slowly builds up to a clear lameness might be avoidable with easy access objective motion measurement devices (OMDs). An early detection of a disorder affecting the locomotor apparatus will lead to an early diagnosis and directed treatment to avoid chronic, irreversible damages to the tissues often caused by long-drawn inflammation (Jansson 1996). A decrease in performance will in most cases lead to a lameness examination to conclude if it is caused by pain. Biomechanical research has revealed that measurements of vertical motion asymmetry of the head, withers and pelvis detect lameness with high sensitivity (Rhodin *et al*. 2018; Buchner *et al*. 1996). Lameness is traditionally detected by subjective evaluation, but low to moderate agreement has been shown between veterinarians *(*Keegan *et al*. 2010) as well as an effect of bias (Arkell *et al.* 2006). For visual lameness assessment, the vertical movement of the poll and the sacrum/pelvis are commonly used by veterinarians. These points have been proven to be the most secure points of lameness evaluation (Buchner *et al.* 1996; Bell *et al.* 2016). With OMDs smaller asymmetries can be detected (McCracken *et al.* 2012). These sensitive OMDs have given rise to the question whether smaller asymmetries are correlated to pain or if they are just a biological variation (Van Weeren *et al.* 2017).

Vertical asymmetry metrics must be understood in the context of functionality and performance. It is therefore of great interest to study performing horses in association to competition. Up to now, measurements of motion asymmetries have relied on body mounted equipment. The emerging development of Computer Vision technology has made it possible to use a smartphone to record gait asymmetry in horses from a distance (Wang *et al.* 2021). The technological accessibility makes it even more important for the equine research community to investigate the functional importance of vertical motion asymmetries.

Several studies have investigated the prevalence of motion asymmetries in different horse populations, revealing that asymmetries above clinically used thresholds are very common, ranging from 73-90% in mature riding horses, youngsters, endurance horses, standardbred trotters and polo horses (Rhodin *et al.* 2017; Wrangberg 2017; Lopes *et al.* 2018; Pfau *et al.* 2016; Kallerud *et al.* 2021). In the search for the relevance of mild and moderate motion asymmetries, the relation to a high performing locomotor system is of particular interest. Therefore, studying horses that are judges to be "fit to compete" for high level events could provide insight.

1.2. Aims of the study

The aim of this study was to investigate the degree of vertical motion asymmetry of Eventing horses during the horse inspection at a long format FEI competition. By describing the level of asymmetry in horses which were given a "pass" judgement by the FEI veterinarians we aimed to evaluate the usefulness of the objective gait analysis tool and to retrieve a range of values describing horses which are put in the holding box or for reinspection. We aimed to receive data regarding the difference in degree of motion asymmetry of the horses in the "pass" compared to the "holding" group. By comparing asymmetries during the first, compared to the second horse inspection during this FEI event we wanted to investigate if the strenuous workload of the cross-country affected motion asymmetry of the horses on a group level.

1.3. Anticipation

The author's anticipation was that horses presented at the horse inspection, which were sent to holding box / reinspection would have a higher degree of asymmetry compared to those that were given a pass judgement.

The author also anticipated that the horses (as a group) would become more asymmetrical after the cross-country ride, comparing the measurements of the first horse inspection to the one after the cross-country.

The author hypothesised that the horses would become more asymmetrical, have a higher total asymmetry, at the second horse inspection after performing the strenuous cross-country discipline.

2. Literature review

2.1. Definition of lameness

There are different ways to define lameness. One definition found in the literature is “Lameness is an indication of a structural or functional disorder in one or more limbs or the axial skeleton that is evident while the horse is standing or at movement” (Baxter & Stashak 2020). Another definition states that “Lameness is simply a clinical sign, a manifestation of the signs of inflammation, including pain, or mechanical defect that results in a gait abnormality characterized by limping” (Ross & Dyson 2010). The definition might sound easy, but the reality is much more complex.

2.2. Veterinary examination of the gaits

2.2.1. The stride cycle

When learning about gait evaluations one must understand how the horse is moving its legs in the stride cycle. One full stride is defined as when all legs have gone through the stride cycle generating one full stride forward. The cycle of each of the four limbs includes the stance phase and the swing phase (Barrey 1999). The swing phase begins the moment the hoof is elevated of the ground and ends when the hoof makes contact with the ground. The stance phase is the time when the hoof has contact with the ground (Bosch *et al.* 2018). The poll and the sacrum/pelvis are the segments of the upper body, which have received most attention in the literature since their vertical movement is of interest to assess lameness (Buchner *et al.* 1996). Their vertical motion is expected to be symmetrical within a stride, when measured in symmetrical gaits, e.g. walk and trot (Barrey 1999). Both the poll and the sacrum moves up and down twice during a complete stride cycle, in trot (Bosch *et al.* 2018). They reach their lowest vertical position during the mid-stance phase of one limb and its highest position during the swing phase or around the impact of the next limb (Kramer *et al.* 2004).

2.2.2. Evaluation of the gaits

When doing a standard evaluation of the gaits at a veterinary examination, the veterinarian is responsible for the inspection and makes a subjective analysis of the movements. When a lameness is suspected there are different scales that can be used to grade the severity of the lameness. In the United Kingdom a scoring system from zero to ten is used where 0 is sound and 10 indicates a complete loss of function of that limb. The American Association of Equine Practitioners scale (AAEP) is from 0 to 5, where 0 indicates sound and 5 minimal weight-bearing of the limb. The AAEP-scale is often split into 0,5 intervals to get a more sensitive grading (Arkell *et al.* 2006). When evaluating the gaits, the veterinarian usually observes the horse in walk and trot on a straight line, followed by lunging on the circle on both hard and a softer surface. Additionally, the exam often includes flexion tests. When an asymmetry is suspected, diagnostic anaesthesia should in most cases be used as a tool to investigate if the asymmetry is related to pain and/or to localize the anatomical site/structure causing the asymmetry (Baxter & Stashak 2020).

In response to pain in a limb, horses change their movement pattern by shifting weight away from the painful limb. That painful limb will then generate less force against the ground, causing an asymmetry. This can be accomplished by changing the vertical movement of the head and pelvis, change in joint angles for example lack of fetlock extension. Although the most consistent change of motion is the vertical movement of the head and poll with front limb disorders, and the movement of the sacrum/pelvis with hind limb disorders (Baxter & Stashak 2020).

The vertical motion asymmetries can be classified depending on when during the limb cycle they occur. Impact asymmetry, or weight bearing asymmetry is when it occurs during the mid-stance phase. Less weight is put on the affected limb causing the horse to sink down less as it is in the load acceptance phase of the limb during the stance phase. Push off asymmetry is by some authors said to be evident when the limb is in the swing phase and is most easily seen just when the limb leaves the ground (Baxter & Stashak 2020). In commonly used lameness metrics, the push off asymmetry is described as a decreased height reached by the head or pelvis at the end of the swing phase of the affected limb. The force producing this upward push is however evidently generated by the limb during stance.

In addition to these two types of asymmetries mentioned above, horses may have a mixed pattern, when the asymmetry is evident both as an altered vertical minimum position during stance and altered vertical maxima at the end of the swing phase (Baxter & Stashak 2020).

Compensatory asymmetries are also important to take into consideration (Baxter & Stashak 2020). Compensatory asymmetry means that an alteration of the movement in the front (front limb lameness) may lead to an asymmetry of the pelvis and vice versa; that a hind limb lameness can cause a head nod (Kelmer *et al.* 2005).

When ipsilateral asymmetry or lameness is present, the primary problem usually originates from the hind limb. The disorder of the hind limb causes a compensatory ipsilateral front limb lameness due to the horse shifting its weight forward onto the diagonal front limb, which makes it look like a front limb lameness on the ipsilateral limb. The compensatory lameness of the front limb is a bit more complex, it causes a compensatory push off lameness/asymmetry of the diagonal hind limb (Kelmer *et al.* 2005). In addition to a primary front limb lameness, the horse will shift its weight to the diagonal hind limb causing the pelvis to sink lower than the opposite side´s hind limb, ipsilateral to the affected front leg. This in turn will result in a false mild ipsilateral impact lameness (Kelmer *et al.* 2005, Uhlir *et al.* 1997).

The risk of missing the primary source of the alteration in symmetry might be less when adding an OMD to the examination process. Specifically the motion of the withers has been shown to help discriminate a false compensatory head nod from a true primary lameness (Rhodin *et al.* 2018).

2.3. Objective lameness measurement systems

The objective measurement systems can be divided into kinetics and kinematic methods. Kinetic systems measure forces that are generated during motion such as the vertical ground reaction force. One system which has been imperative to the understanding of compensatory lameness mechanisms is a treadmill with integrated force sensors (Weishaupt *et al.* 2002).

Kinematics on the other hand measures the movements of specific body segments. The movement can be measured using accelerometers or more complex inertial measurement units (IMUs) which are mounted over specific anatomical landmarks of the horse´s body. The IMU contains three accelerometers, gyroscopes and magnetometers. Several systems are available on the market. Commonly they measure the head, pelvis and limb motion. Lameness Locator, Equigait and Equimoves are examples of this type of OMD (Keegan *et al.* 2011; Pfau *et al.* 2016; Bosch *et al.* 2018). Other kinematic systems use optical sensors to collect motion data. This includes both multiple high speed camera systems that track the position of spherical reflective markers which are placed on the horse's skin (Hardeman *et al.* 2020), or computer vision methods tracking the horses motion from marker less key point detection (Wang *et al.* 2021).

Objective measurements of vertical motion asymmetry of the horse's head and pelvis are useful proxies for uneven loading of the limbs at trot. With body-mounted inertial sensors and the computer vision based OMD used in this study, displacement data are measured over multiple sequential strides. The collected data are processed including filtering and deselection of non-representative motion. The horse shaking its head, uneven footing, or a playful horse, leads to the need of a filtering technique to avoid outliers. The optimal cut-off frequency is crucial for a reliable result (Bragança *et al.* 2020). OMDs measure the vertical displacement of the poll and the pelvis and cut the data stream in segments each including a full stride. Data from one stride takes the form of a double sinusoid curve with two minima and two maxima. The minima represent the vertical position of the poll or pelvis around mid-stance of the left and right limb respectively, corresponding to the time of full vertical loading of the limb. The maxima are instead the result of the upwards push from the ground and occur when the hoof/leg is around the end of the swing phase. A large enough difference of the left respectively the right leg, between the stride minima and maxima, indicate either an impact or push off asymmetry or lameness respectively (Bell *et al.* 2016).

The four most used asymmetry metrics extracted from each measurement include the head difference minima (HDmin) indicating weight bearing asymmetry between the fore limbs, head difference maxima (HDmax), the pelvic difference minimum (PDmin), showing the difference in pelvic minimum positions between left and right hind leg mid stance and the pelvic difference maximum (PDmax) describing the difference between left and right hind leg upwards push. Some devices provide these metrics in actual millimeters while others relate the asymmetry metrics to the total vertical range of motion (RoM) of the head or pelvis respectively. These data together with the sinusoidal curves help the observer to understand if the asymmetry is a push off or impact lameness and helps determine which leg is affected. An asymmetry of the head giving a relevant HDmin value, indicates a front limb impact lameness, HDmax- front limb push off lameness. PDmin- hind limb impact lameness and a deviating PDmax indicates a hind limb push off lameness (Keegan *et al.* 2011).

The measurements are important since they provide an evidence based diagnostic tool to the lameness work up. This is needed to overcome the restricted time resolution of the human visual system, the limited agreement between veterinarians (Keegan *et al.* 2010) as well as expectation bias (Arkell *et al.* 2006). The technology allows detection of asymmetries that are smaller than the perception limits of the human visual system. Therefore, the question of the relevance of such asymmetries arises and has started a discussion among veterinarians. Concerned voices state that lameness evaluations are complex, and measurements of asymmetry need to be put in context with more variables and other clinical signs. Others agree and stress that OMDs should not replace the veterinarian but should be used as an aid in the complex evaluations (Van Weeren *et al.* 2018).

2.3.1. Gait analysis using computer vision

The possibility to utilize an OMD without body mounted sensors was investigated by (Wang *et al.* 2021). The development of computer vision and machine learning has made it possible for visual tracking systems to recognize and track posture and specific points of a moving object via ordinary video recordings even when the background is complex (Zhou & Hu 2008). Wang *et al.* (2021) tested different deep learning models to identify one that reliably could identify the horses´ body parts via video recordings made by e.g. mobile phones. The system used has to be trained to recognize the specific points of the horse´s body which the researcher is interested in, for motion asymmetry analysis that is the poll and pelvis (Wang *et al*. 2021).

The OMD used in the present study (Sleip AI) is an iOS application that can analyse the motion of the horse from a video recorded by a mobile phone using markerless tracking.

2.4. Motion asymmetries

Many recent studies using objective motion measurement devices (OMDs), have revealed that vertical motion asymmetries are prevalent in our working horse populations even though the horses are regarded as healthy by the riders and trainers. Out of 222 medium to novice level riding horses in full training, 73% were found to have vertical motion asymmetries comparable to horses with low to moderate degree of lameness (Rhodin *et al.* 2017).

Furthermore, a master thesis study looking at the prevalence of movement asymmetries in young riding horses that had not been broken in alternatively not yet been excessively trained, found that 36 out of 49 horses (73.5%) displayed an asymmetrical movement pattern similar to mild clinical lameness. The hypothesis of the study was that the prevalence of movement asymmetries would be lower than those seen amongst older horses since the younger horses have not been exposed to the overloading that can be caused by training and have not yet been affected by the asymmetries and laterality of the rider. There were 50 horses in the ages between 2-5 years of age, considered not lame by the owners, included in the study. The results stated the movement asymmetries corresponds to previous collected data from older horses and the hypothesis was thereby rejected. Although more data needs to be collected in order to be able to draw any significant conclusions (Wrangberg 2017).

Endurance horses have been studied using an OMD (Lameness Locator) during a FEI endurance race. In this study 21 of 22 horses were detected with an irregular gait. A significant disagreement between the OMD and the Fédération Equestre Internationale veterinarians (FEI- veterinarians) was detected but was no longer detected after reducing the sensitivity of the OMD by reclassifying horses with mildly irregular gait as sound (Lopes *et al.* 2018). Another study looking at polo horses in training showed that 60–67% of horses would be classified with movement asymmetry above threshold guideline values for either the forelimbs, hind limbs or both (Pfau *et al.* 2016).

Trotters start their training young and undergo intense training to be able to race as 2 or 3-year- olds. A study was looking at how different training programs affected the horses' locomotion symmetry. Both subjective and objective evaluation methods were used. The study recruited and studied one-year old trotters just being introduced to training. These horses were divided into two groups with different training regimes, one control training program (group C) and one with 30% reduced intensity (group R). The groups of horses were followed for 2,5 years, during this time the horses went through nine clinical examinations and were measured with an OMD 17 times. The results showed that days lost to training defined as "days when a horse was not trained as planned (reduced partly or completely) due to not being fit for training based on the trainer's opinion or veterinary recommendation" were lower in group R, while maintaining the performance compared to the C-group. They could also see that asymmetries in locomotion apparatus increased during the time when the horses were being introduced to new high intensity training regimes, for example as the 3-years -olds were introduced to exercises uphill. The conclusion of the study was that by reducing the intensity, days lost to training could be reduced and with the help of an OMD adjustment in the training could help avoid causing orthopedic problems (Ringmark *et al.* 2016).

Also, young trotters have been studied at the start of their training using an OMD. The study showed that 90% showed motion asymmetries above clinically used thresholds, but that gait variability for each horse was substantial. When a study is carried out on such young horses, the age has been suggested to influence the result. Incoordination, weakness and growth are parameters that cannot be discarded as irrelevant to the results showing a high percentage of asymmetry (Kallerud *et al.* 2021). More studies are needed to understand if gait asymmetries in performing horses is a biological variation and/or laterality or a sign of lameness.

Laterality is described as "a preference to use one side of the body". Riders often describe horses having one side that is easier than the other to work with. What laterality means in scientific terms is an asymmetry in the nervous system functions as a result of cerebral lateralization where one side's hemisphere is dominant, thus resulting in a preferred side (Rogers 2009). Horses with a preferred dominance of the right hemisphere are more prone to react with the fight, flight, fright- response and are more likely to be “reactive horses” (Rogers 2010). This innate laterality has appeared to be relatively resistant to training, whilst preferred locomotor patterns might be corrected with the help of correct training (Rogers 2010). Without diving further into this phenomenon, it is found in other animal species (Rogers 1989) but it is not yet fully investigated on a population level whether horses have an innate laterality due to the nervous system’s structure or not. This makes it relevant when assessing asymmetries in horses, and to differentiate between a physiological and a pathological asymmetry is important, as well as difficult (Byström *et al.* 2020). Laterality in riding horses is even more complex due to the part the rider or handler might play in it all. The rider might be asymmetrical, hence putting uneven load on the horse while sitting in the saddle. The contact and tension in the rains might play a role as well, with uneven tension it might cause the horse to work in an asymmetrical manner building muscles unevenly which can cause both asymmetry and eventually with loading the body’s structures unevenly, it may result in lameness as well (Byström *et al.* 2020). Factors other than training and innate laterality, which can be contributing to motion asymmetry, can be shoeing and conformation (Van Heel *et al.* 2006). Different length of the limbs and different heights of the hooves has shown to be a possible cause of different loading of the limbs and an asymmetrical movement (Vertz *et al.* 2018) . When a hind limb was made higher, the upward movement of *tuber sacrale* was affected resulting in something looking like a push off asymmetry (reaching a lower maximum hight) of the limb contralateral to the one that had been lifted up (the shorter limb). In the study they concluded that asymmetry of the hind limbs can be caused by uneven trimming or shoeing (Vertz *et al*. 2018).

Laterality is difficult to pinpoint and there is no protocol for laterality detection, nor is there any defined criteria to say which side is the dominant side in the horse (Williams 2011). But studies to detect limb preferences has shown that the dominant front limb is protracted when foals are grazing (Van Heel *et al.* 2006).

2.5. Agreement between veterinarians regarding subjective lameness evaluation

Studies have shown that the agreement between veterinarians regarding lameness assessment in horses varies. A study from 2010 found that if a lameness was >1.5 on the American association of equine practitioners’ scale (AAEP lameness scale), the agreement was 93.1%, but when it was < 1.5 the agreement was 61.9%. The study also stated that when having to tell whether the horses were lame or not and deciding which leg was the worst after a full evaluation, the agreement was 51.6%.

This led to the conclusion that regarding horses with a mild lameness, subjective evaluations are not quite reliable (Keegan *et al.* 2010).

One study compared subjective lameness evaluation with an OMD, Lameness Locator. In this study they found that the OMD detected an asymmetry, an induced lameness, earlier than the veterinarians executing the subjective evaluation. In 58% of the trials the OMD detected an asymmetry earlier, in 8% of the trials the veterinarians detected an asymmetry first and in 20% of the trails the OMD and the veterinarians detected it at the same time. This indicates that with the help of an objective measurement devise, subtle lameness can be detected earlier, which may lead to a quicker identification of the affected area and may prevent further damage to the affected structure (McCracken *et al.* 2012).

A study evaluating intra and inter-observer agreements of "fit to compete" judgements between FEI veterinary delegates found that inter-observer agreement was 58% during live evaluations. Intra-observer agreement between the first live evaluation and the recorded version at one and 12 months was 71%. An objective analysis system was recording the movement at the same time. The motion capture data was processed using designated software (QHorse v1.0a, Qualisys AB, Motion Capture Systems, Göteborg, Sweden). In this study twelve horses in regular low-level dressage and pleasure riding were included and evaluated according to the FEI horse inspection procedure for jumping competitions by three FEI veterinary delegates. Sensitivity and specificity of motion symmetry measured with quantitative gait analysis system were 83.3% and 66.7% respectively, against the consensus of all observers as a reference. The results from this study suggest that more FEI veterinary delegates should be used to adequately judge fit-to-compete and that quantitative-gait-analysis may be useful to support decision making during fit-to-compete judgement. The study also shows that quantitative gait analysis has an acceptable sensitivity and specificity to detect motion asymmetries that are taken into account when judging fitness to compete (Serra Bragança *et al.* 2020).

In a study looking at agreement between veterinarians in lameness assessment, it was observed that classification of sound horses can be difficult. The results showed that 72% correctly classified the horses as sound regarding the front limbs, but only 28% correctly classified the horses as sound regarding the hind limbs. This was due to participants incorrectly seeing a hind limb lameness where there was none. The study used videos with animated horses made perfectly symmetrical. The study stated that regardless of the veterinarians background, it is difficult to make a reliably differentiation between mildly lame and sound horses (Starke & Oosterlinck 2019).

A recent study looking at horses in full training that were considered free from lameness by the trainers/riders, showed vertical motion asymmetries measured with an OMD. They were treated with non-steroidal anti-inflammatory drugs (NSAIDs) and in this case Meloxicam. A total of 82 of the 140 horses showed asymmetric movement, 66 of these horses were included in the study. The treatment with meloxicam could not be proven statistically significant in trot on a straight line or on the lunge, and no significant effect of treatment could be seen in the most asymmetric horses. This could be due to a biological variation or laterality. Or it could be due to that the meloxicam treatment was not sufficient enough for the disorder causing the asymmetry (Persson Sjödin 2020). More studies like the previously mentioned are needed to fully understand the clinical relevance of the milder asymmetries detected by the very sensitive OMDs now available. Studies to investigate the prevalence of asymmetries in the performing horse population to better understand the relevance of such asymmetries are of interest as well.

3. Materials and methods

3.1. Study protocol and study population

One eventing show of the long format, Pratoni del Vivaro, Italy, held in November 2021, was picked out based on several criteria: the number of participating horses was expected to be high, several classes (from 1*-4*) including high-level athletes were expected at the event and a geographical convenience sample was made based on travel efficiency from Sweden. Due to lack of time, more events were not possible to include in the study. Horses at the event were included based on if a consent form could be signed by a horse representative to allow the horses participation and if consent to film the handler was achieved in order to comply with GDPR regulations. Out of all available horses (n =114) participating in the long format eventing competition, 58 had consent forms filled and were included. Of the 58 horses, 44 were trotted up at the second horse inspection after the dressage and cross-country. Information about the horses' age, breed and gender was collected from the FEI-database. Information about level of performance for this event, (1*, 2*, 3* or 4*) was provided by the show organisation. There were 25 geldings, 5 horses referred to as male, 9 stallions and 19 mares. All horses were Warmblood riding horses except one who was a Thoroughbred. The age distribution was between 5-18 years (median 9 years). The distribution of level of performance was 1* =18 horses, 2* =19 horses, 3* =15 horses and 4* =8 horses at the first horse inspection before the event started.

The first horse inspection took place on day one of the event. The second horse inspection took place at the end of the event on day four, after the dressage and cross country was performed but before the show jumping.

3.2. Materials

An Iphone (model Iphone 12 Pro), a tripod and the mobile phone application Sleip AI, was needed for the data collection to take place. A study key, if needed to identify the horse in the data, was kept using paper and pen during the horse inspection, documenting the individual horse id correlated to the number of the video saved in Sleip AI. This was later transferred to a document on a computer.

3.3. Study approval by the FEI

The study was approved by the FEI before data collection started. An application was submitted to the FEI including the full study plan and the consent forms.

3.4. Consent, GDPR and confidentiality of data

Three different consent-forms were made and had to be singed before a horse could be included in the study, enabling use of the data for the study purpose. The handlers running with the horse by hand signed a consent form to allow their appearance on the video (complying with GDPR). The person responsible for the horse/rider signed a consent form to allow the data from the horse to be used in the study. And finally, the FEI official signed a consent form to allow the use of the subjective evaluation of when a horse was assigned pass or reinspection / put in holding box. The GDPR consent was signed at the show office at arrival. The other two consent forms were personally presented to riders and FEI officials by the study-coordinator and author of this study. All horse data were pseudonomised at data entry into the gait analysis system and the video footage of horse and handler were deleted at the end of the study period, only key point motion data were securely stored after study conclusion.

3.5. Motion recordings using the mobile phone application

Motion recordings were performed while the horses were being routinely evaluated by the FEI-officials during the two horse inspections; before the competition start on day one, and before the final competition event on day four –the show jumping. No data were shared with the official FEI veterinarian in order to avoid bias. A tripod with an Iphone attached at eye height was placed at the trot up area, centred in the middle at the opposite end of the trot up line in relation to where the FEI veterinarian would observe the horses at the horse inspection. The tripod was placed 4 meters from where the horses were turning and then trotting back. The trot-up line was 31.5 meter long, with turning-place included. The footing was asphalt with sand put on top for the occasion. The data collection did not need any sensors to be put on the horses, the mobile phone application collects data by measuring the movements of the poll and the sacrum of the horse via the recorded video material. The tripod was placed at the same spot for all evaluations. The researcher was standing behind the tripod to press “record” and “stop”. The videos were saved locally on the smart-phone and were uploaded and analysed when a stable WiFi could be accessed. In the mobile phone application, the horses were identified as horse Pratoni 1, horse Pratoni 2, etc. A key to horse identity and horse details was kept in a separate computer and stored SLU’s servers to allow the ability to provide the riders with measurement details if they would want to take part of the results. The identity key of the horses will be discarded after data analysis is performed (at the latest at the end of the study).

All data that could lead to identification of horses, competitors or officials was kept confidential. To avoid biasing the FEI officials, competitors and official FEI veterinarians were not able to get access to the results of the evaluations during the show.

3.6. Asymmetry analysis using Sleip AI

The video material was recorded and analysed using the mobile phone application Sleip AI, a gait analysis tool based on marker-less motion detection performed by artificial neural networks

The video recordings are securely transferred to the cloud servers where neural network optimized hardware completes the full sequence of calculations and postprocessing in 2.5-3 minutes. The neural networks detect the horse in the image, the horse’s activity and performs markerless tracking of multiple body segments as the horse is trotting.

To secure analysis validity for the use by veterinary professionals the processing pipeline will not produce validated results of recordings with less than 10 strides and will warn the user about the analysis certainty if < 35/25 strides are included for front /hind limbs respectively. For the recordings in this study all files were accepted for the automated analysis, irrespective of a low number of strides.

3.6.1. Asymmetry grading by Sleip AI

Sleip AI divides asymmetries into very mild, mild, moderate and severe. It calculates the asymmetry size in relation to each stride’s range of motion (RoM). The classification is for the front legs: difference (diff) <8% of RoM =very mild, < 20% of RoM =mild, < 40% of RoM =moderate, < 60% of RoM = severe.

For the hind limbs: difference < 5% of RoM =very mild, < 12.5% of RoM =mild, < 25% of RoM =moderate, < 37.5% of RoM =severe. Sleip AI then converts this to a number on a scale form 0 till 2. The asymmetries are shown in colour in the phone app as green (no asymmetries of relevant size detected) grey (very mild), yellow (mild), orange (moderate) and red (severe). The thresholds are as follows: for very mild =0.2, mild =0.5, moderate =1, severe =1.5.

We decided to count all horses with an asymmetry mild and above to represent horses with relevant degree of asymmetry in this study. This was based on our clinical experience with the tool for gait monitoring and lameness assessment purposes. At the level "mild" the authors find the asymmetry to be consistently detected by the eye. This "threshold" was used for investigation of prevalence of motion asymmetry in horses deemed "fit to compete".

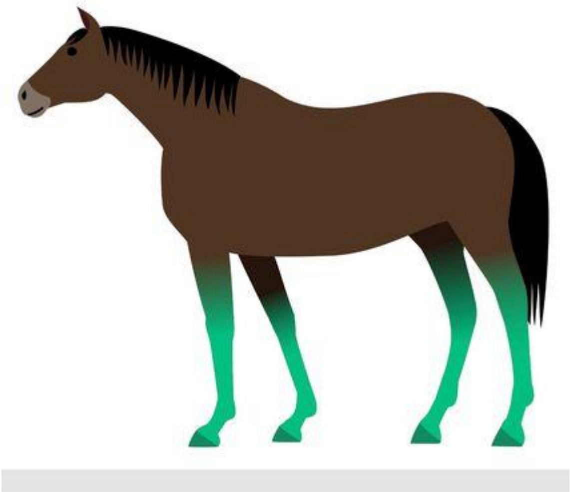

Figure 1: A simplified output from the app Sleip AI demonstrating a horse without detected asymmetries (Reproduced with permission from Sleip AI.).

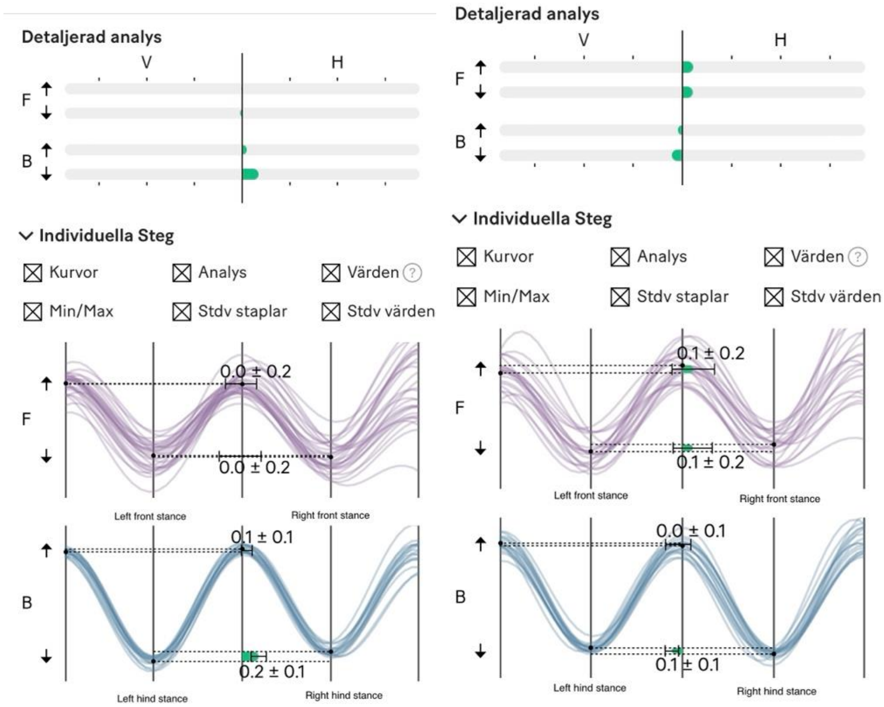

Figure 2: Two different figures of the vertical motion of head (purple) and pelvis (blue) in two different horses showing relatively symmetrical sinus curves. Each double sinusoid represents the motion during a stride as the horse loads and pushes of from the left and then the right limb. These horses will be pictured as green in the simplified summary (Figure 1) indicating that no asymmetry of relevant size was detected (Reproduced with permission from Sleip AI.).

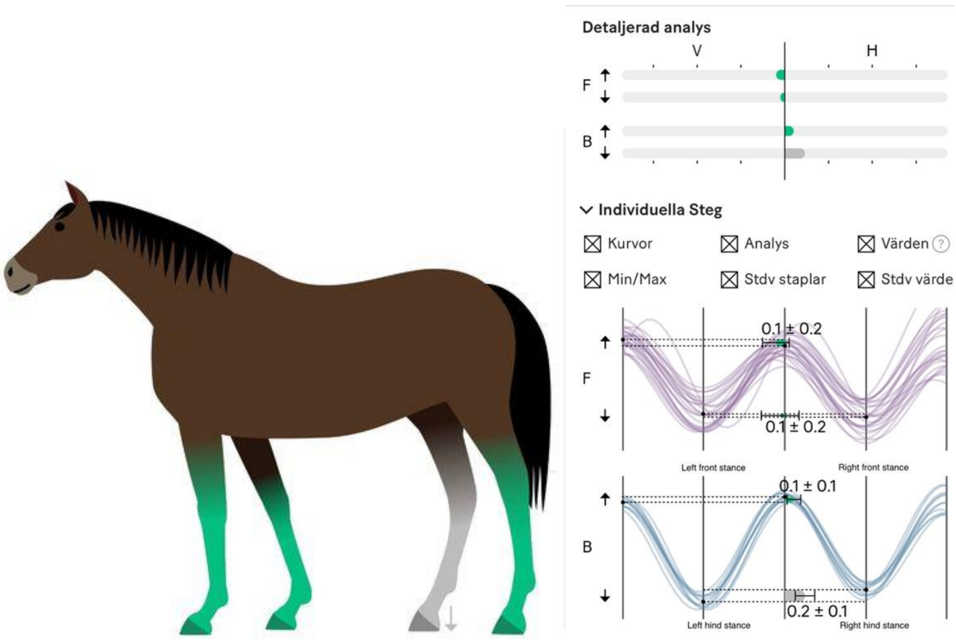

Figure 3: A simplified output from Sleip AI of a horse with a very mild right hind limb impact asymmetry. To the right, graphs of stride data show the same horse's sinus curves of the vertical motion of head (purple) and pelvis (blue). Each double sinusoid represents the motion during a stride as the horse loads and pushes of from the left and then the right limb (Reproduced with permission from Sleip AI.).

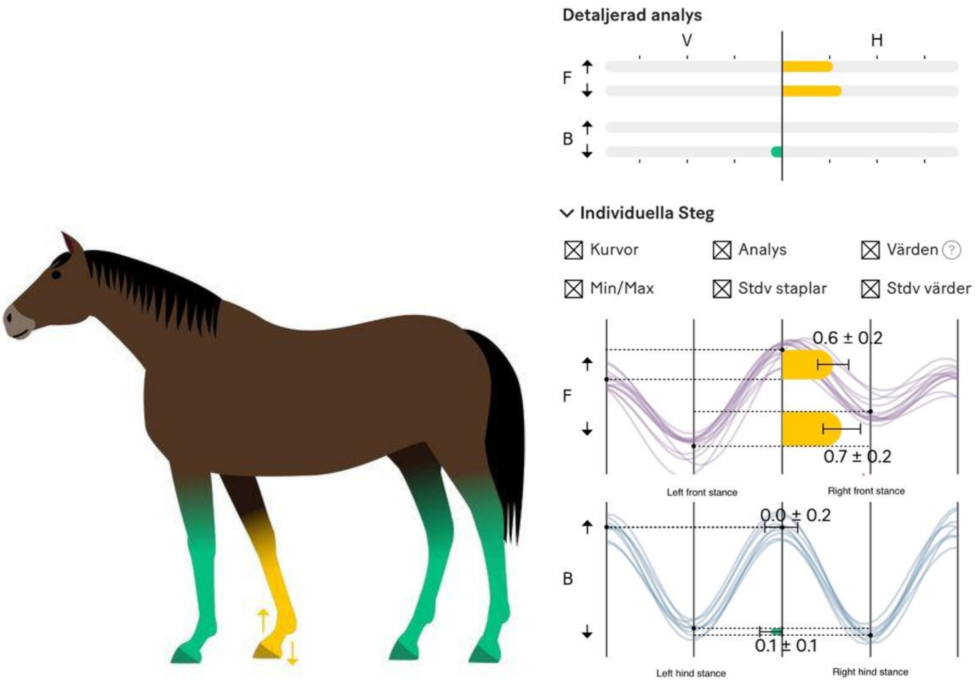

Figure 4: A simplified output from Sleip AI of a horse with a mild front limb asymmetry, both impact and push off. To the right, graphs of stride data show the same horse's sinus curves of the vertical motion of head (purple) and pelvis (blue). Each double sinusoid represents the motion during a stride as the horse loads and pushes of from the left and then the right limb (Reproduced with permission from Sleip AI.).

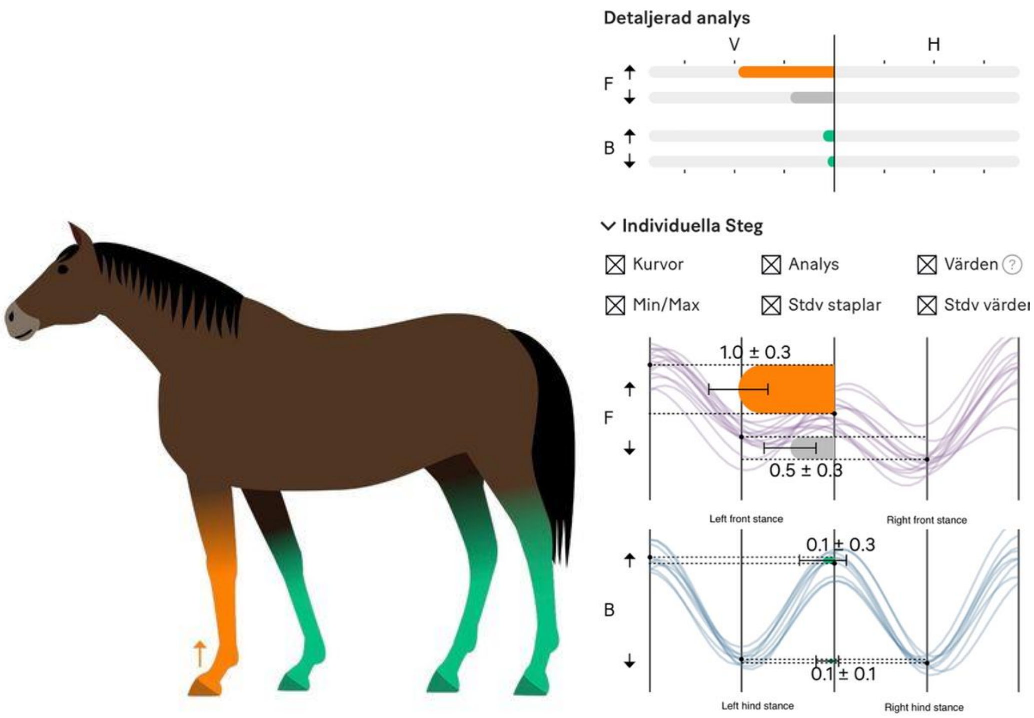

Figure 5: A simplified output from Sleip AI of a horse with a moderate front limb asymmetry. Moderate push off and very mild impact asymmetry. To the right, graphs of stride data show the same horse's sinus curves of the vertical motion of head (purple) and pelvis (blue). Each double sinusoid represents the motion during a stride as the horse loads and pushes of from the left and then the right limb (Reproduced with permission from Sleip AI.).

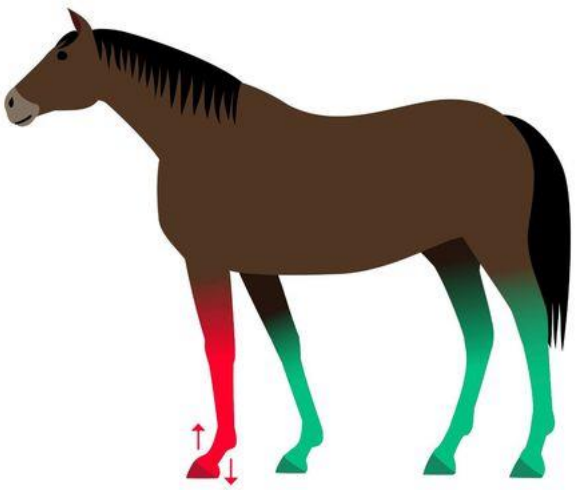

Figure 6: A simplified output from Sleip AI of a horse with a severe front limb asymmetry (including both impact and push off components) (Reproduced with permission from Sleip AI.).

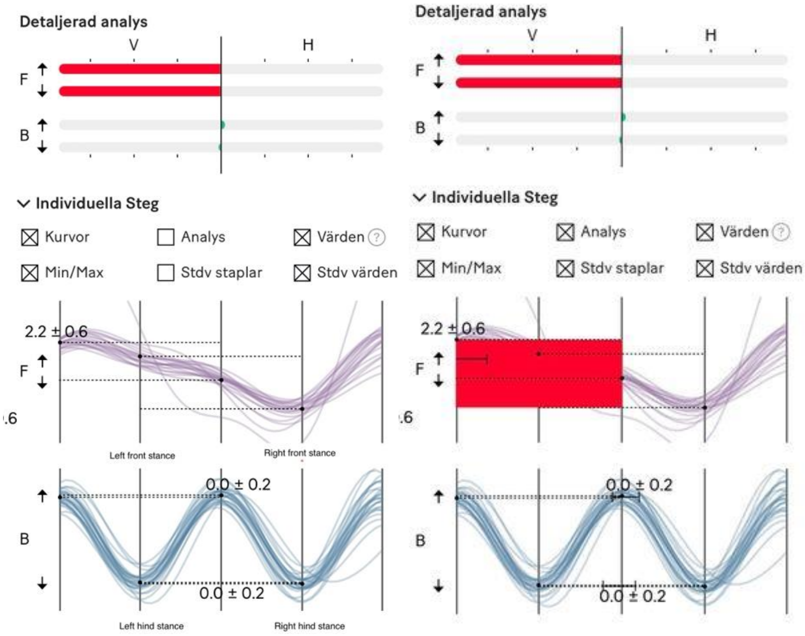

Figure 7: The stride curves with asymmetric sinusoidal shape from the horse in figure 6, which had a severe impact and push off asymmetry of the left front limb. The vertical motion of head (purple) and pelvis (blue). Each double sinusoid represents the motion during a stride as the horse loads and pushes of from the left and then the right limb (Reproduced with permission from Sleip AI.).

3.7. Data compilation and statistical methods

All data collected were compiled in Microsoft excel. For each horse and for each horse inspection, horse-inspection 1 (HI1) and horse-inspection 2 (HI2), data of the number of analysed strides front, HDmin, standard deviation (SD)-HDmin, HDmax, SD-HDmax, number of analysed strides hind, PDmin, SD-PDmin, PDmax, SD-PDmax and total asymmetry was assembled. The horses' data were divided into whether they were a straight away "pass" at HI1, "holding" at the first run HI1, "fail" after holding HI1, pass post holding HI1. The same for the second horse inspection: "pass" HI2," holding" after first run HI2, "fail" after holding HI2, pass post holding HI2. Descriptive statistics were calculated. Excel was used to calculate the standard deviation, mean and median. These calculations were made using the absolute values of the asymmetries. This means that the statistics does not show if the asymmetry derives from the left or right limb (negative values indicates left limb asymmetry).

A total asymmetry was calculated for each horse, meaning the sum of all the scores of asymmetries of all four legs.

Wilcoxon signed rank test was performed using IBM SPSS statistics, to test if there was a difference in total asymmetry at a population level between the first and second horse inspection.

3.8. Contributor notes

The supervisor of this study (Elin Hernlund) is one of the founders of Sleip AI, which is owned by the founders, SLU Holding and a few unpaid minority shareholders. The author of this study (Jonna Martinsson) is one of these minority shareholders. No financial support for this study was obtained from Sleip AI.

4. Results

At the first horse inspection (HI1) 58 horses participated. Horses that got a straight away “pass” HI1 were =53, horses that first went to “holding” but got a “pass” after being shown a second time =4, and horses that got a “fail” after holding and a second run HI1 =1. Total pass post HI1 =57.

At the second horse inspection (HI2) 44 horses were shown. The loss of horses was (n =13) due to poor results in the cross-country or unknown reasons. At HI2, horses that got a “pass” were =42, “holding” =2, “fail” =0. The two horses that were sent to holding were eventually given a “pass” which means that all 44 horses had a final judgement of a “pass” at HI2.

4.1. Descriptive statistics of motion asymmetry

Box plots were made to show the distribution of absolute values for HDmin, HDmax, PDmin, PDmax between all the groups and between the first and second horse inspection (Figures 8-11). The box plots show the median value, upper and lower quartile, the arithmetic mean value marked as an x, and outliers. Figure 12 demonstrates the total asymmetry, the sum of all asymmetries of all four legs put together, in each group during HI1 and HI2.

The horses that got the decision “holding” had to trot up once again for a new evaluation due to an uncertainty whether they were fit to compete or not. The measurements from the group called “holding” is the run that got the horse sent to the holding box.

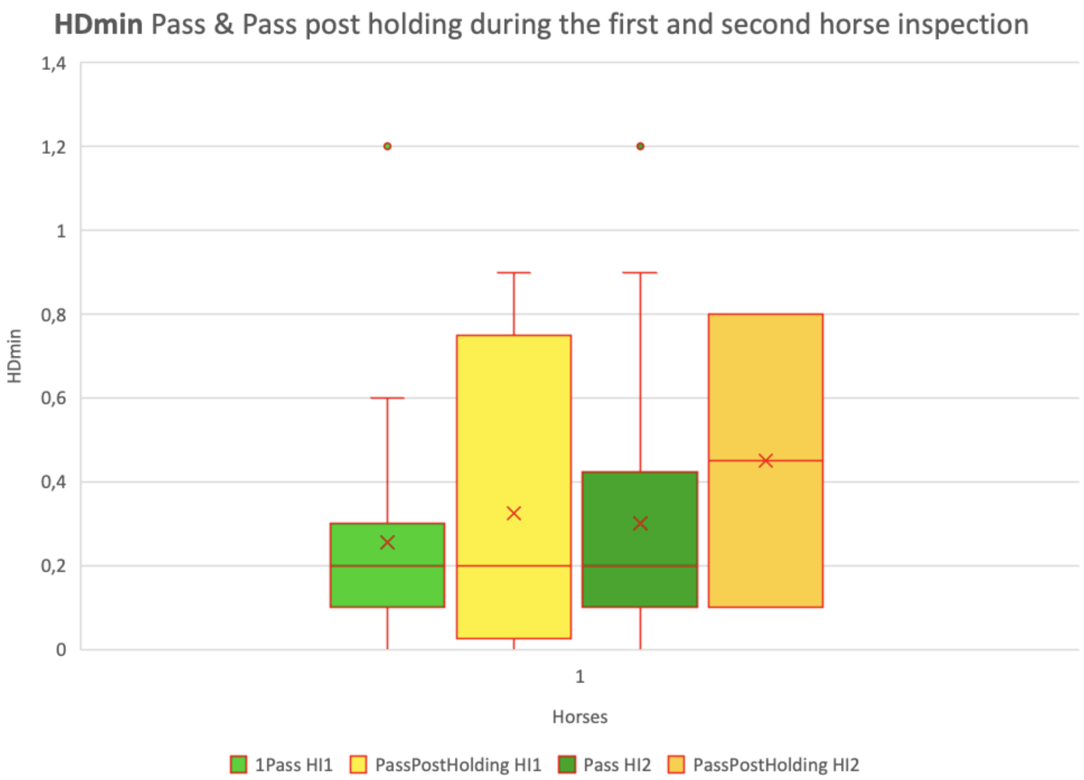

Figure 8: Box plot demonstrating the HDmin of all the runs that generated a" pass" during the first horse inspection (HI1) & second horse inspection (HI2). "Pass post holding" means the runs of the horses that was shown a second time after their first run that generated a "holding". "Pass" HI1 n=53, Pass post holding HI1 n=4. "Pass" HI2 n=42, Pass post holding HI2 n=2. Mean number of strides for all measurements was 11.8.

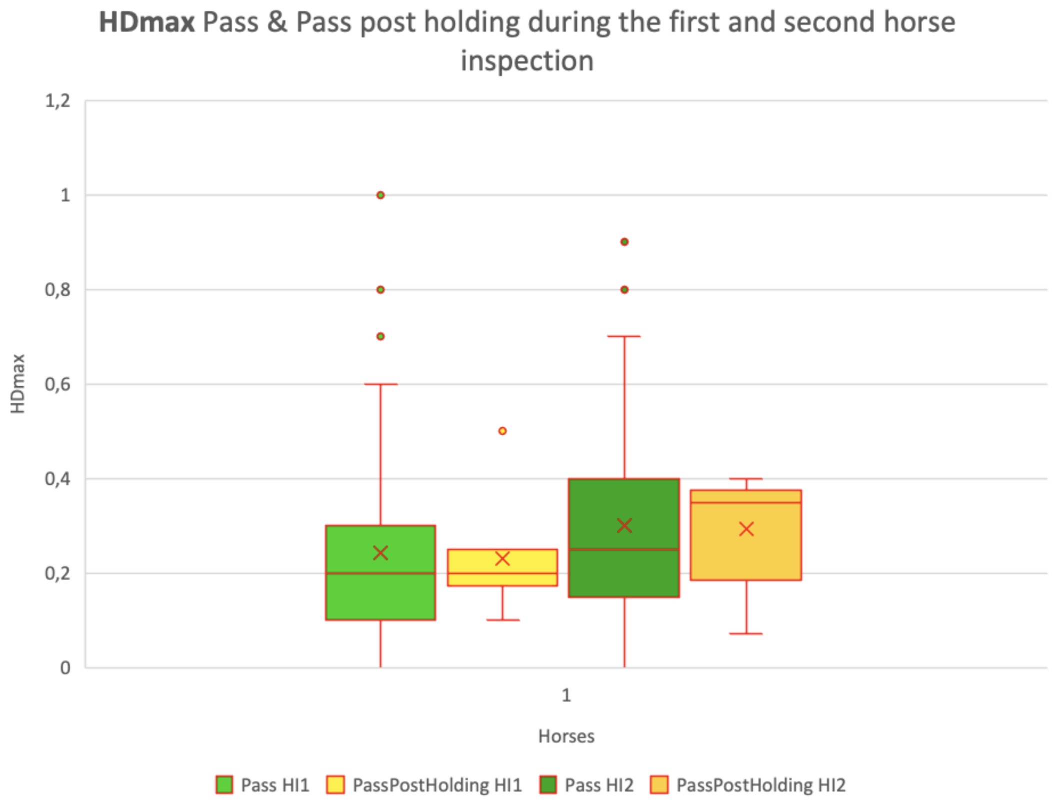

Figure 9: Box plot demonstrating the HDmax of all the runs that generated a" pass" during the first horse inspection (HI1) & second horse inspection (HI2). "Pass post holding" means the runs of the horses that was shown a second time after their first run that generated a "holding". "Pass" HI1 n=53, Pass post holding HI1 n=4. "Pass" HI2 n=42, Pass post holding HI2 n=2. Mean number of strides for all measurements was 11.8.

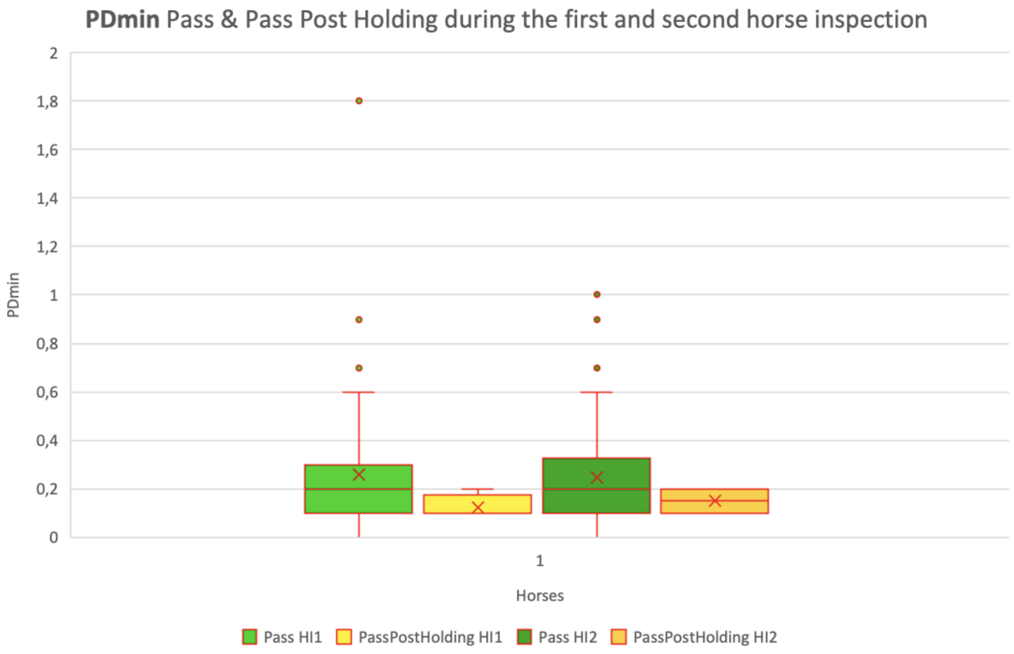

Figure 10: Box plot demonstrating the PDmin of all the runs that generated a" pass" during the first horse inspection (HI1) & second horse inspection (HI2). "Pass post holding" means the runs of the horses that was shown a second time after their first run that generated a "holding". "Pass" HI1 n=53, Pass post holding HI1 n=4. "Pass" HI2 n=42, Pass post holding HI2 n=2. Mean number of strides for all measurements was 7.4.

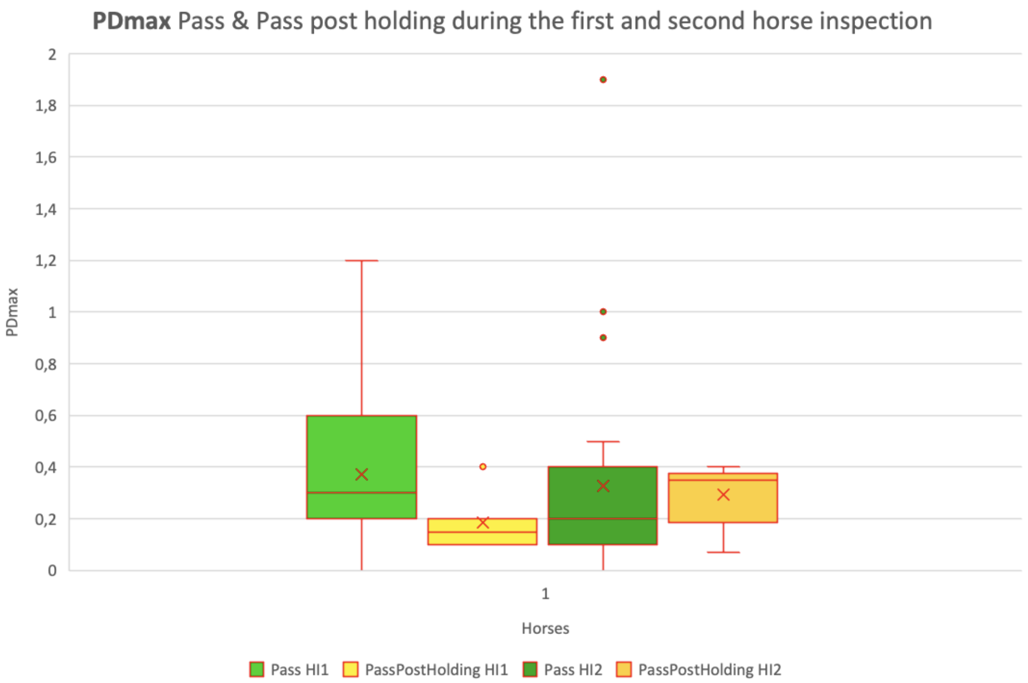

Figure 11: Box plot demonstrating the PDmax of all the runs that generated a" pass" during the first horse inspection (HI1) & second horse inspection (HI2). "Pass post holding" means the runs of the horses that was shown a second time after their first run that generated a "holding". "Pass" HI1 n=53, Pass post holding HI1 n=4. "Pass" HI2 n=42, Pass post holding HI2 n=2. Mean number of strides for all measurements was 7.4.

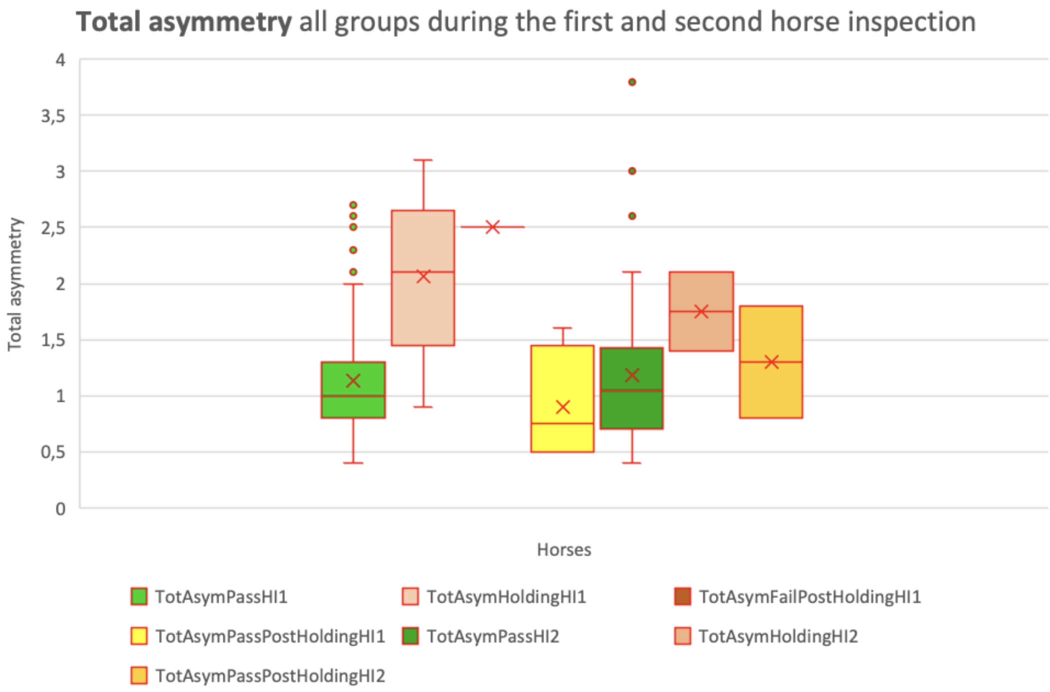

Figure 12: Box plot demonstrating the total asymmetry of all the groups of horses during the first (HI1) and second horse inspection (HI2), including the runs generating to "holding" and the one that led to a complete non pass. "pass" HI1 n=53, "holding" HI1 n=5, "pass post holding" HI1 n=4, fail post holding HI1 n=1. "pass" HI2 n=42, "holding" HI2 n=2 "pass post holding" HI2 n=2, "fail post holding" HI2 n=0

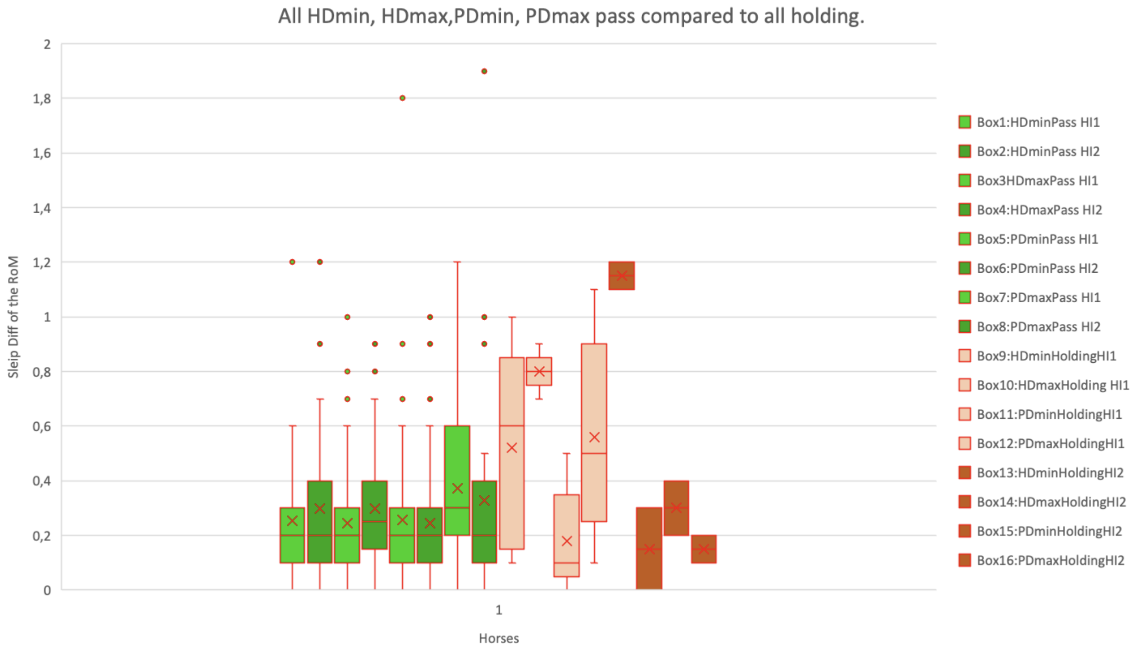

Figure 13: Picture demonstrating the distribution of all HDmin, HDmax, PDmin, PDmax for the runs generating a "pass" compared to "holding" during the first and the second horse inspection. Pass HI 1=lighter green boxes. Holding HI2= brown boxes. Number of horses sent to holding were few compared to the ones that passed. Holding HI1 n=5, Holding HI2 n=2. Pass HI1 n=53, Pass HI2 n=42.

4.1.1. Number of analysed strides

The analysed number of strides varied. Table 1-2 gives an overview of the number of analysed strides in each group.

Table 1: Number of analysed strides for the front and hind limbs for each group during the first horse inspection.

	Mean Front (strides)	Median Front (strides)	SD Front (strides)	Mean Hind (strides)	Median Hind (stride)	SD Hind (strides)
HI1 Pass	11.81	12	2.75	7.40	7	1.82
HI1 Holding	12	11	2.83	7,4	8	1.95
HI1 Pass Post Holding	11.5	10.5	3.87	9	9.50	1.41

Table 2: Number of analyzed strides for the front and hind limbs for each group during the second horse inspection.

	Mean Front (strides)	Median Front (strides)	SD Front (strides)	Mean Hind (strides)	Median Hind (strides)	SD Hind (strides)
HI2 Pass	12.26	12	2.07	8.43	8	1.76
HI2 Holding	11	11	2.83	7.50	7.50	2.12
HI2 Pass Post Holding	12.5	12.5	0.70	10.5	10.5	0.70

4.2. Prevalence asymmetry mild and above

Out of the 58 horses at the first horse inspection 21 (36%) had an asymmetry of mild degree or more on at least one leg during the runs generating a “pass”, not taken into consideration if it was a front or hind limb, push off or impact asymmetry. The tables below show data in a more detailed manner, how many had a push off asymmetry versus an impact and so on.

Table 3: Prevalence of asymmetry in the different groups during the first horse inspection, stratified by severity of the asymmetry and if impact (min) or push off (max) asymmetry. The horse who got a "fail" is included in the "HI1 Holding".

	Mild HDmin	Moderate HDmin	Severe HDmin	Mild HDmax	Moderate HDmax	Severe HDmax	Mild PDmin	Moderate PDmin	Severe PD min	Mild PDmax	Moderate PDmax	Severe PD max
HI1 Pass	4/53 7,5%	1/53 1,8%	0	7/53 13,2%	0	0	5/53 9,4%	0	0	11/53 20,8%	2/53 3,8%	0
HI1 Holding	2/5 40%	1/5 20%	0	5/5 100%	0	0	1/5 20%	0	0	2/5 40%	1/5 20%	0
HI1 Fail	0	1/1 100%	0	1/1 100%	0	0	0	0	0	0	0	0
HI1 Pass Post Holding	1/4 25%	1/4 25%	0	0	0	0	0	0	0	0	0	0

Table 4: Prevalence of asymmetry in the different groups during the second horse inspection, stratified by severity of the asymmetry and if impact (min) or push off (max) asymmetry.

	Mild HDmin	Moderate HDmin	Severe HDmin	Mild HDmax	Moderate HDmax	Severe HDmax	Mild PDmin	Moderate PDmin	Severe PDmin	Mild PDmax	Moderate PDmax	Severe PDmax
HI2 Pass	7/42 16,6%	2/42 4,8%	0	7/42 16,6%	0	0	6/42 14,3%	0	0	4/42 9,5%	2/42 4,8%	1/42 2,4%
HI2 Holding	0	2/2 100%	0	0	0	0	0	0	0	0	0	0
HI2 Pass Post Holding	1/2 50%	0	0	0	0	0	0	0	0	0	0	0

Table 5: The prevalence of asymmetry of mild type or more during the first horse inspection in the different groups. In these numbers below (Table 5-6), it is not considered if the asymmetry was a push off or an impact asymmetry, but mainly how many had an asymmetry in the front versus the hind legs.

	Front	Hind
HI1 Pass	12/53 (22.6%)	17/53 (32.0%)
HI1 Holding	5/5 (100%)	4/5 (80%)
HI1 Pass Post Holding	1/4 (25%)	0

Table 6: The prevalence of asymmetry of mild type or more during the second horse inspection in the different groups. Not taken into consideration if impact or push off asymmetry.

	Front	Hind
HI2 Pass	16/42 (33.3%)	13/42 (31.0%)
HI2 Holding	2/2 (100%)	0
HI2 Pass Post Holding	1/2 50%	0

4.3. Change in total asymmetry

From the total asymmetry a comparison between the first and second HI was made looking at how many horses improved their total asymmetry/got a decrease in total asymmetry, got a worsening/increase of the total asymmetry, or remained unchanged. This does only tell us about the total asymmetry (the summed absolute asymmetry from all four legs), not if a worsening was on the same initial leg or if the asymmetry changed to another leg or spread to multiple legs but with less high difference in RoM on one particular leg.

At HI2 23/44 (52%) horses improved their total asymmetry, 16/44 horses (36%) had a worsening of total asymmetry at HI2 and 5/44 (11%) remained unchanged in their total asymmetry at HI2.

Wilcoxon signed rank test was performed using IBM SPSS Statistics to test the difference in total asymmetry at a population level between the first and second horse inspection. No statistical significance in difference of the total asymmetry could be seen (p =0.77, test statistic 369.5).

Table 7: Change in total asymmetry from the first to the second horse inspection after the dressage and the cross country.

Improved tot. asym.	Worsening tot. asym.	Unchanged tot. asym.
23/44 horses (*52%)*	16/44 (*36%)*	5/44 (*11%)*

4.3.1. Level the horses competed at, in relation to improved, worsening or unchanged in total asymmetry:

We also looked at the distribution of change in asymmetry between the different levels. These numbers describe how may in each group of improvement/worsening/unchanged were competing at 1*, 2* 3* and 4* level.

In the second HI horses on 1* level =16, horses on 2* level =12, horses 3* level =10 and horses 4* level = 6 (Table 8). In the 1-3* level, half of the horses or more, improved their total asymmetry from the first to second HI.

Table 8: Table showing the change in total asymmetry for each competition level (1-4*).*

Level	Improved tot. asym.	Worsening tot. asym.	Unchanged tot. asym.
1*	10/16 62.5%	5/16 31.3%	1/16 6.3%
2*	6/12 50%	5/12 41.7%	1/12 8.3%
3*	5/10 50%	3/10 30%	2/10 20%
4*	2/6 33.3%	3/6 50%	1/6 16.7%

5. Discussion

In this study we described the vertical motion symmetry in Eventing horses presented at the horse inspection of an international FEI eventing competition of the long format of 1*-4* level, as presumed “fit to compete”. It is, to our knowledge, the first study of vertical motion symmetry in a group of horses of the discipline Eventing at this level, and the first test of if movement symmetry changed from the first to the second horse inspection.

In total, 58 horses were recorded using a computer vision tool for gait analysis at the horse inspections at one FEI eventing competition of the long format. At the first horse inspection, 36% of the horses that “passed” showed asymmetry of mild type or more, on one leg or more.

In spite of the high exercise load during the cross country, 52% of the 44 horses presented at the second horse inspection (after the cross country) improved their total asymmetry, 36% had a worsening/increased total asymmetry and 11% remained unchanged in their total asymmetry level. The level of measured asymmetry using the gait analysis app was higher in the few horses which were given a non-pass on their first trot up (sent to holding) compared to the ones that were subjectively judged to be fit to compete and were given a “pass”. Horses that got a straight away “pass” at the first horse inspection had a median of 0.95 of total asymmetry. The runs that generated a “holding” decision, had the median of 2.1 of total asymmetry at the first horse inspection. At the second horse inspection the “pass” had a median of 1.05 and the “holding” a median of 1.75. The difference in total asymmetry between “pass” and “holding” was not tested statistically due to the low number of individuals in the “holding” group.

Some horses with high degree of asymmetry slipped through the “pass”. Objective gait analysis can be useful in order to pick these horses out for a second control. A mean of 11.8 trot strides were recorded for the front limbs during the first horse inspection and 7.4 trot strides for the hind. During the second horse inspection a mean of 12.2 trot strides were measured for the front limbs and 8.5 for the hind. In order to render a more reliable interpretation of the gait analysis, more trot steps should be recorded. This could be made possible if the trot up was longer.

With the developing techniques of objective motion measurements, hopefully soon the active "horse people population", trainers, riders and caretakers, can with the help of an OMD, routinely check the horses to earlier detect orthopedic problems. The techniques could be used to adjust the training to avoid overloading and provide indications when the horses might benefit form at lower intensity training for a period of time to recover fatigued structures.

5.1. Limitations

In this study we decided to measure the horses while being routinely evaluated at the horse inspection even though we knew this would likely not generate enough strides to get completely reliable measurements. But since this is the actual number of strides the veterinary officials are presented with in order to make a decision of a "pass" or "holding", we decided to use the standard set up and not ask for a longer trot-up or additional rounds of trot. Other studies only include data with around 25 analysed strides or more (Keegan *et al.* 2010). This is something I would like to highlight to the reader.

The study included few horses that were judged to fail the horse inspection. Therefore, a statistical analysis of the objective asymmetry levels in relation to the visual classification was not deemed suitable. The data however indicate that the horses who failed or were sent to re-inspection had more elevated levels of asymmetry.

When looking at an asymmetry increase of a horse or group of horses in terms of the total asymmetry, we don't know if the horse got more asymmetrical on one specific limb, which could indicate an increased lameness, or if the total asymmetry could become worse due to a low increase of asymmetry from several limbs which might be more complicated to interpret as a clear increase of lameness.

5.2. Reflections on results

An interesting result was that 52%, of this specific group of horses, improved their total asymmetry form the first to the second horse inspection, despite having gone through both the dressage and the cross-country, there was however no significant change on a population level that could be seen (Wilcoxon signed rank test, p = 0.77).

In terms of catching an early orthopedic problem, one could look at the horses that had increased asymmetry on the same leg from the first to the second horse inspection. The knowledge of this change to the worse on the same limb, might be an important piece of information for the rider as they after the event can take the time to do a vet check of the horse at home. An example is this horse in the figure below (figure 14), who had an ipsilateral asymmetry (very mild) during the first horse inspection. But during the second HI the horse had a mild ipsilateral asymmetry (figure 15). These horses that got an increase in the asymmetry from HI1 could maybe benefit of a follow up at home after the event.

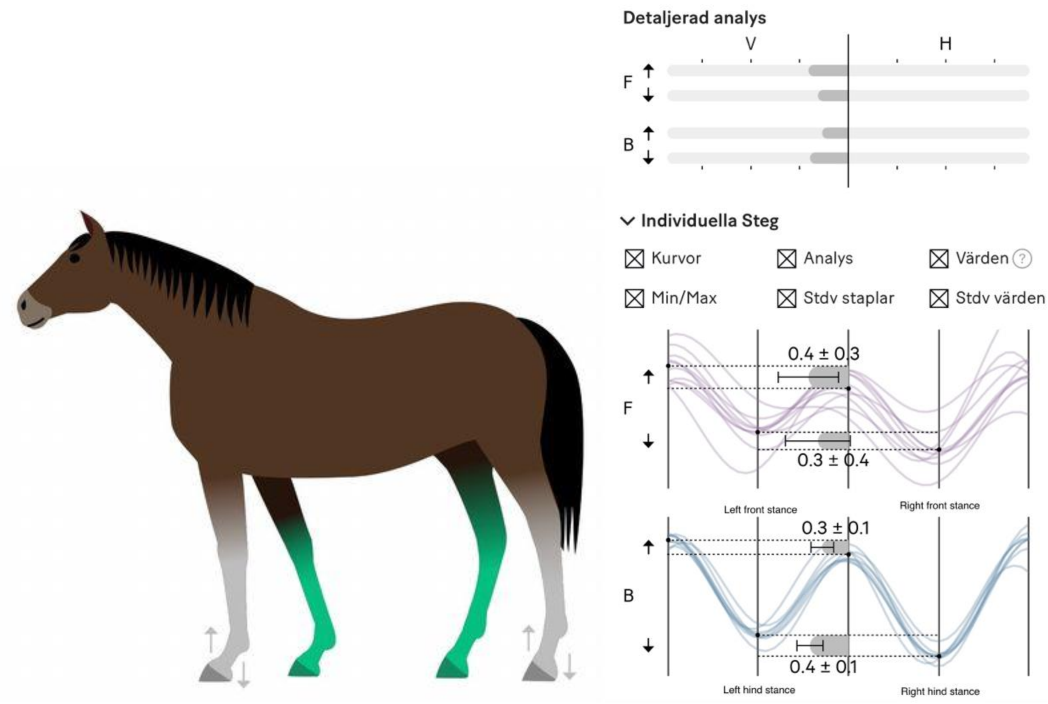

Figure 14: Figure demonstrating a horse during the first horse inspection with a very mild ipsilateral asymmetry, left front left, left hind leg. To the right the sinus curves of the vertical motion of head (purple) and pelvis (blue) to the same horse. Each double sinusoid represents the motion during a stride as the horse loads and pushes of from the left and then the right limb (Reproduced with permission from Sleip AI.).

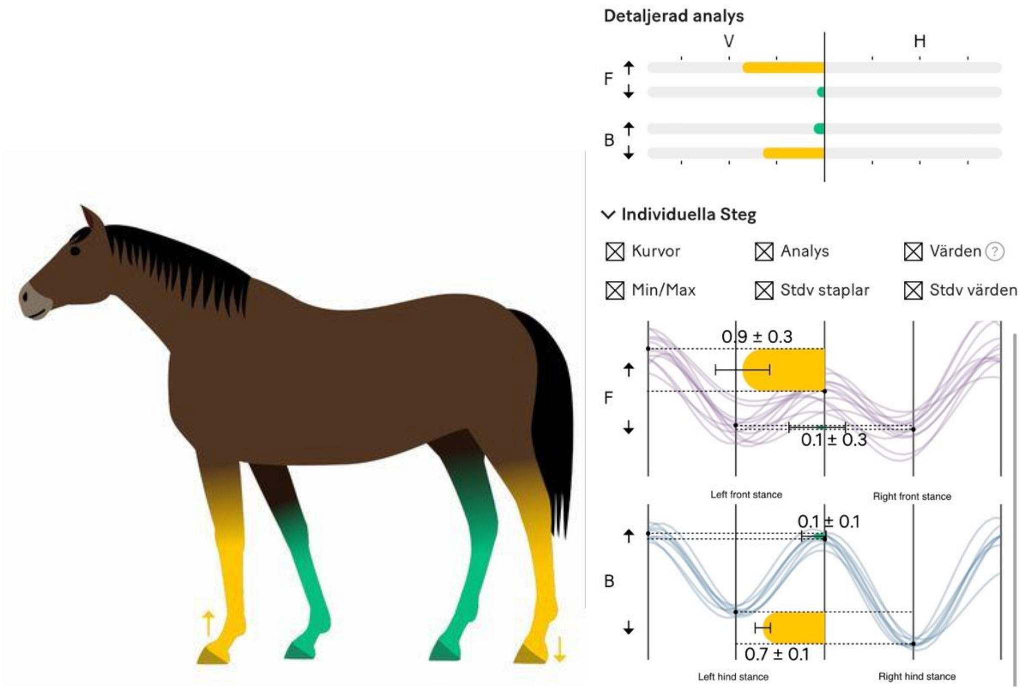

Figure 15: The same horse as in figure 14 but after the second horse inspection. An increase in the same asymmetry as seen during the first horse inspection is detected. This might be a horse who would benefit from a follow up at home after the event. The rider/ owner would benefit from this information as well since it might help catch an incipiently problem (Reproduced with permission from Sleip AI.).

It is not possible to say if the horses with an increased asymmetry during HI2 would have a joint or soft tissue problem, of if they simply had some lateralised muscle soreness from the heavy cross-country. That's why a follow up would be ideal for these horses that increased their asymmetry at HI2. General muscle soreness would not likely cause a clear asymmetry, but rather generalized stiffness.

Looking at the prevalence of asymmetry of the classification mild and above during the first horse inspection only, it showed that 21/58 horses (36%), during the runs generating a "pass", had an asymmetry on one leg or more, of mild type or more severe. In other studies with horses seen as sound by the owners, around 70% were asymmetrical above repeatability thresholds that are used to detect clinical lameness (Pfau *et al.* 2016; Rhodin *et al.* 2017; Wrangberg 2017). Compared to those groups of horses, this group of performing eventing horses at the event Pratoni del Vivaro long format 1*-4* level, might seem less asymmetrical. It is however difficult to compare between studies using different asymmetry measurement systems, since the signal processing differs between the tools. Also, the asymmetry threshold used in this study was set by the research team.

When looking at the asymmetry classified as mild and above, found in the group "pass", the prevalence was higher for the front limbs during the second horse inspection with 33% compared to asymmetry mild and above during the first horse inspection which had a prevalence of 23%. The prevalence for the hind limbs were 32% during HI1 and 31% during HI2. In these numbers are the horses with outliers-data included. That the pass-group still has some horses that with the OMD would classify as mild asymmetry and above, might be due to the fact that the classification "mild" ranges from 0.5 up to 0.9. This means that a horse with for example a HDmin of 0.5 asymmetry might not be as easily detected for the eye, whilst a horse with HDmin 0.9 would be detected much more easily.

One of the questions asked when this study started was if there was possible to find a threshold for when the horses should be sent to holding box, but this could not be concluded in this study due to the limited number of horses studied. To be able to do that, one would have to do the same measurements, as done in this study, during more eventing shows of the long format.

5.3. Outliers

In the different groups there are some extreme values/outliers that got a "pass". I looked closer at some of the horses with the highest degree of asymmetry amongst the outliers in the figures 8-11.

Looking at figure 8 there are two horses with a HDmin that stand out. During HI1 a horse with a HDmin of 1.2 got a "pass" (left front). The same horse had a PDmax 0.8 (left hind) although this run was one of the few measurements that had only 5 strides measured for the front and the hind. But at HI 2 the horse still presented a moderate asymmetry of left front and was sent to holding box. It later got a pass post holding. Even though the number of measured strides was not sufficient during HI1 the horse presented with the same type of asymmetry during HI2 and got sent to holding, so with this in mind, the first analysis during HI1 maybe was not so far off and the horse slipped through HI1 with a moderate asymmetry.

The horse that had a HDmin 1.2 during HI2 had interestingly the same type of asymmetry during HI1 only milder (0.6 mild asymmetry). This is a horse that could have benefit from the information about an increase of the initial asymmetry, and should have been sent to holding HI2. Figures of this horse is shown below (Figure 16-17).

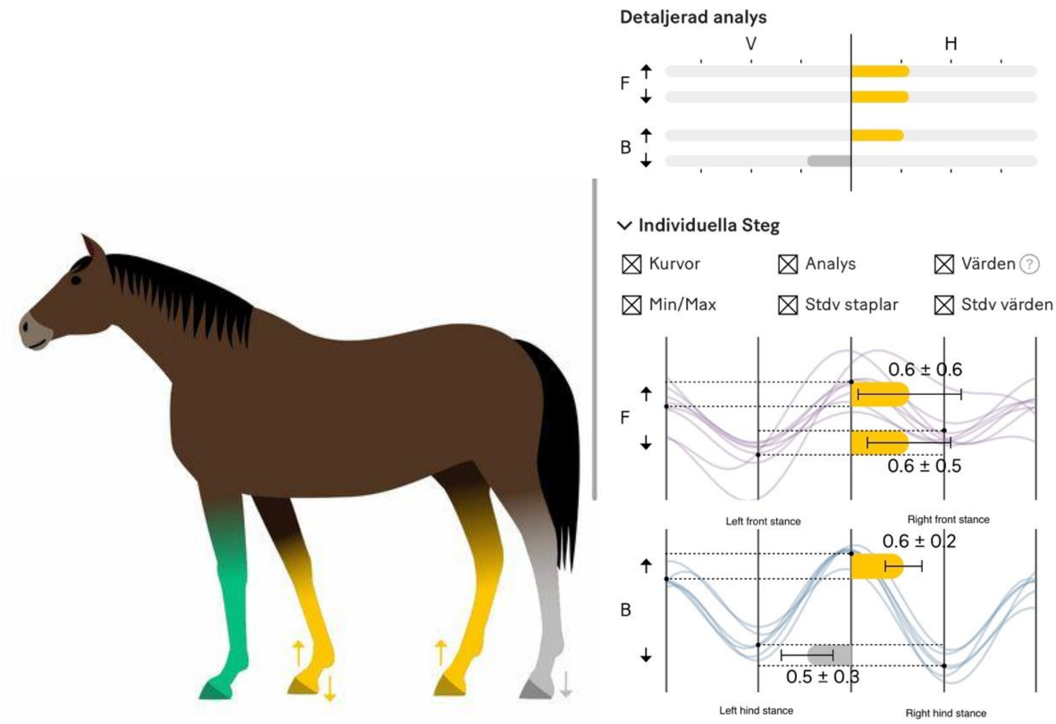

Figure 16: Figure showing the horse during the first horse inspection. The same horse stands out during the second horse inspection with a HDmin of 1.2, shown in the next figure (17) here below (Reproduced with permission from Sleip AI.).

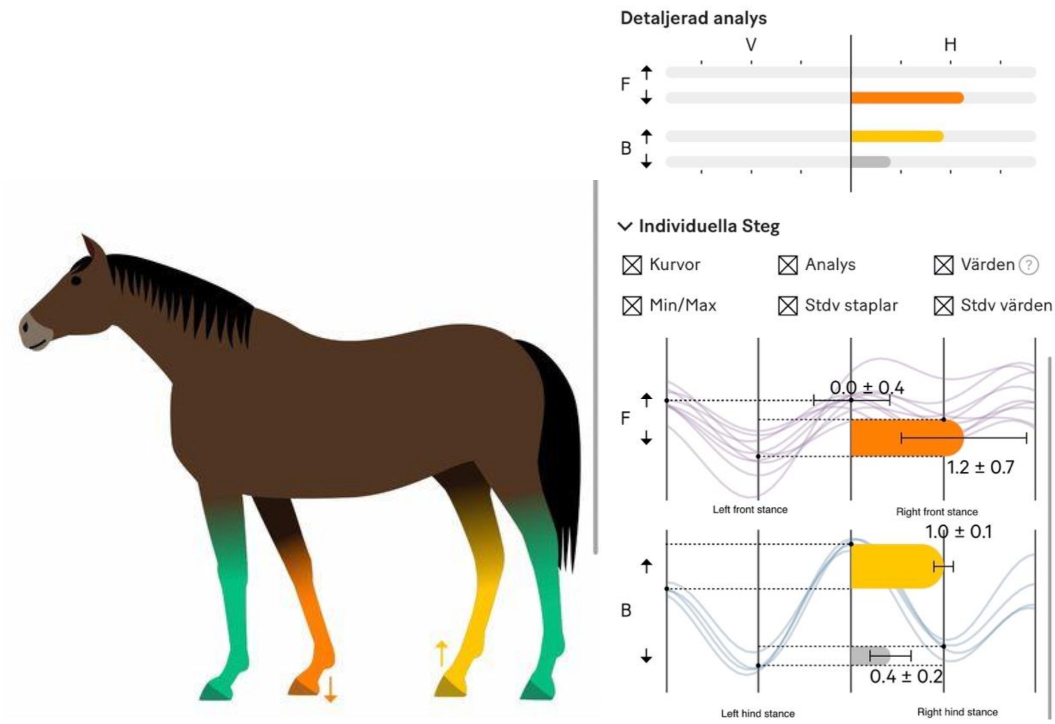

Figure 17: showing the same horse as in the previous figure above but at the second horse inspection where its HDmin stands out as an outlier. Interestingly this horse has had an increase of its initial asymmetry. This horse and rider would probably benefit from this information (Reproduced with permission from Sleip AI.).

Outliers that stand out with a HDmax was a horse during HI1 “pass” with a HDmax of 1. This horse had an improvement of the asymmetry during HI2.

Another horse had a HDmax of 0.8, this run generated quite few strides. To HI2 the horse had less asymmetry of the same limb, 0.5 and 13 analysed strides.

The PDmin that stands out the most is the run generating a PDmin of 1.8 during HI1. This result was due to a very fresh horse jumping around and running with the tail up in the air which made it difficult for Sleip AI to recognise the sacrum.

PDmax had one very high data value during the HI2. This horse had an increased asymmetry of the leg from HI1 which showed only a very mild push off and impact asymmetry of the left hind. During HI2 it had a severe push of asymmetry left hind, mild impact left front and very mild push off asymmetry of right front. It passed, which it should probably not have. It was a white horse, and the sun was out with backlight towards the veterinary staff. This might have made it difficult for the eye to focus on the white sacrum of the horse, although it was very lame. Figures of the horse shown below (Figures 18-19).

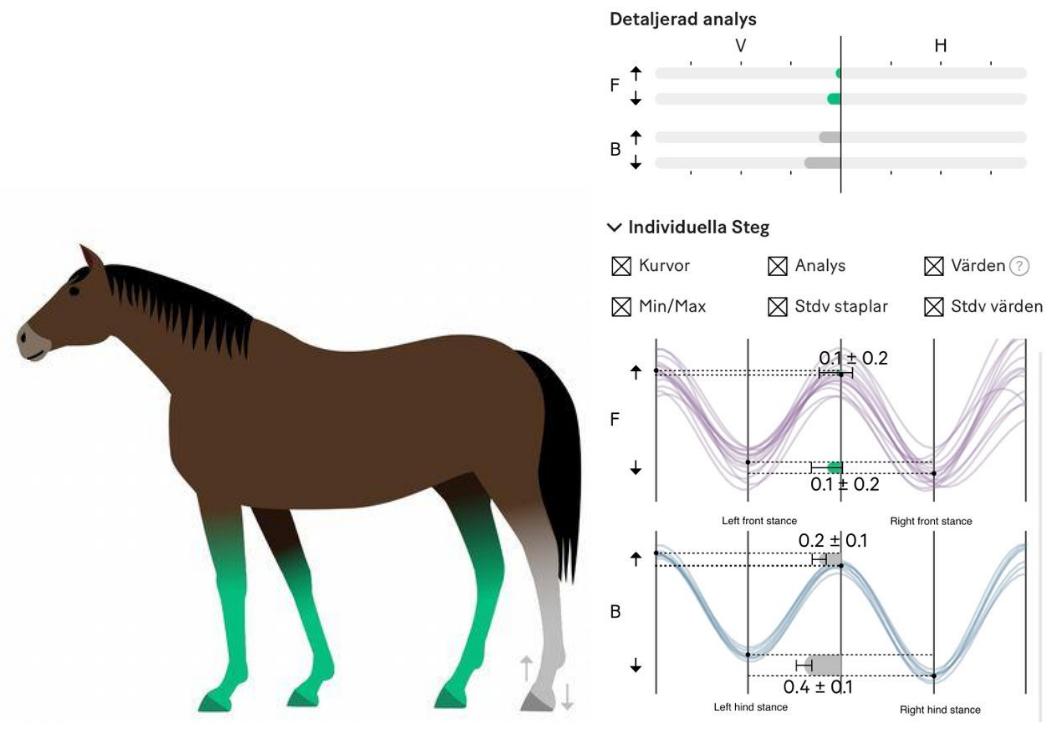

Figure 18: showing the horse who was standing out during the second horse inspection as an outlier of PDmax with a severe asymmetry. This is the same horse during the first horse inspection. Below this figure is the same horse during the second horse inspection (figure 19) (Reproduced with permission from Sleip AI.).

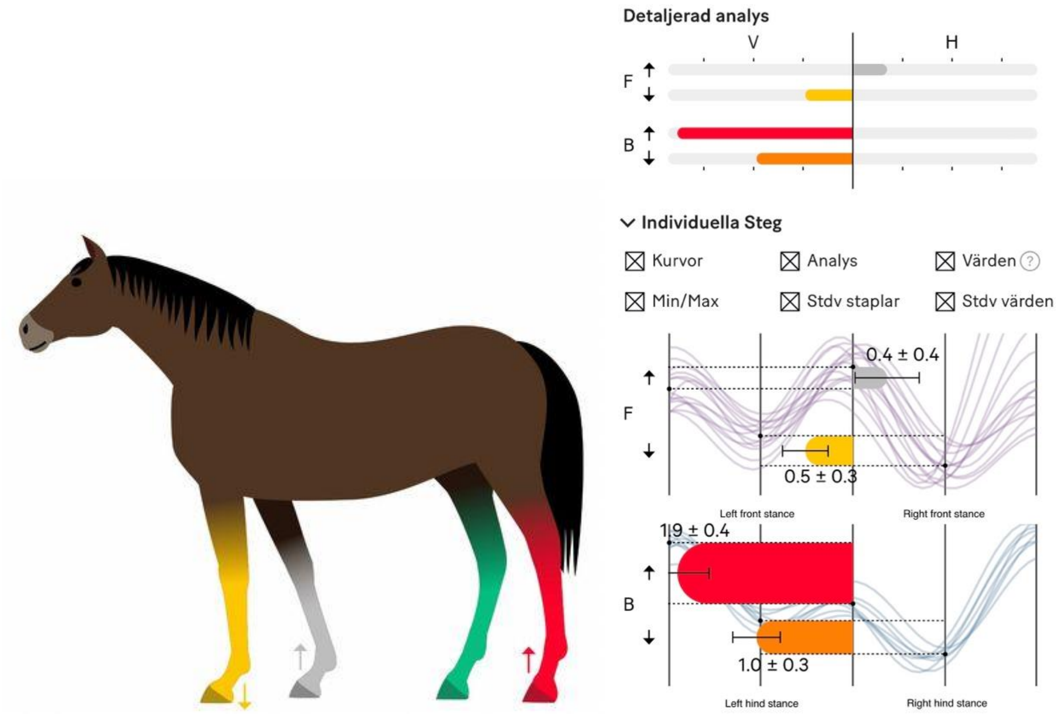

Figure 19: Figure demonstrating the same horse as in the figure above, during the second horse inspection where it had an increased asymmetry of its initial asymmetry on the left hind limb. And other asymmetries as well. This horse should probably not have passed and been allowed to start the showjumping (Reproduced with permission from Sleip AI.).

Looking at these outliers described above, one can tell that many of them, except the ones that had too few strides measured to produce reliable results, had an increase of their initial asymmetry from the first to the second horse inspection. The outliers that slipped through the "pass" were many (3 out of 5) of white/grey colour.

If we look at the outliers in the "pass"-group at the first and second horse inspection in figure 12, demonstrating the total asymmetry jn the different groups, 3/5 outliers during HI1 and 3/3 outliers during HI2 were white/grey coloured horses. This might indicate that it is more difficult to assess the white and lighter coloured horses.

5.4. Asymmetry levels and the subjective judgement

Looking at the total asymmetry, the horses that were sent to holding have a higher total asymmetry than the horses that were a straight away "pass". This is demonstrated in figure 12, but is not tested. There are some outliers in the "pass" group, as described earlier as well.

Looking at Figure 13, with a box plot demonstrating the distribution of all HDmin, HDmax, PDmin, PDmax for the runs generating a "pass" compared to "holding" during the first and the second horse inspection, one can see that Sleip AI and the veterinary officials are agreeing on the higher asymmetry of the horses sent to “holding”. The median of all the asymmetries during the first horse inspection stays second horse inspection (darker green boxes) due to a few more horses with higher extreme values. For the horses that were sent to “holding”, a higher median was seen for HDmin HDmax, PDmax during the first horse inspection. During the second HI the horses sent to “holding” was more asymmetrical with their HDmin. One should remember while reading this box plot the number of horses that were sent to “holding”. Holding HI1 =5, Holding HI2 =2, with more data and horses this could have generated an even more clear view of if the horses sent to holding were more asymmetrical. The data shows that some horses with an asymmetry equal to the horses sent to holding slipped through the straight away “pass”, here the use of an OMD might have helped catch these horses and let them trot up one more time after first been sent to “holding”.

Proper tests of agreement between the official veterinary staff and Sleip AI were not possible due to the low number of horses judged unfit to compete.

5.5. Sleip AI, usability during FEI-eventing competitions

As stated above, we could see that Sleip AI detected a clear asymmetry in horses sent to holding and the horses that failed the inspection. Some horses with a high asymmetry were given a ‘pass’. These horses might have benefitted of being shown a second time, to rule out a more consistent asymmetry that could be relevant to the horse’s health. Here the app Sleip AI could work as an aid to the veterinarian. The horses that had an increased asymmetry of one particular leg during HI2 compared to HI1, could benefit from this information if the person responsible for the horse would do a follow up of these asymmetries that seem to increase after a heavier workload, as after the cross-country.

But to be able to draw more accurate conclusions from the measurements, a change in the routine of the horse inspection would have to be made. The horses would have to run two times up and down the trot up line instead of one time, or have a longer trot up line. This to get more strides analysed.

One important observation made by the author during the data collection was that the internet connection needs to have a certain capacity in order to allow immediate feedback from the analysis. The analysis time is normally a couple of minutes, excluding upload time. To be able to upload and have the video analysed fast enough, the internet connection is vital. During this study the data was first saved locally on the app and uploaded later due to bad internet connection. It might be possible to have a portable wifi-station with to help with the internet issue. Running the app continuously on a phone for many hours uses quite some battery power. The author therefore recommends a portable charger to be connected to the phone during the data collection.

5.6. Take home message

Of the included horses in this study few were sent to holding box (n =7), but these had a larger mean asymmetry compared to those that got a "pass". More horses would have to be included in the study to be able to draw any statistical conclusions from the data.

More than half of the horses presented both at the first and second horse inspection improved (decreased) their total asymmetry, after the dressage and cross-country. Of the horses that had an increase in total asymmetry, many showed a worsening of the same initial asymmetry, which was found at the first horse inspection. The author believes that these horses would benefit from a follow up after the event to check development of the gait pattern and maybe get a vet check to investigate signs of clinical orthopedic issues.

Even if the official veterinarians detected most of the horses with a higher degree of asymmetry, 36% of the horses that got a "pass" during the first horse inspection had an asymmetry on one leg or more that were classified as mild or more by the mobile phone gait analysis system, Sleip AI. The author believes that an objective analysis of motion symmetry could assist the veterinary officials to pick up more of these horses to have them put in "holding" and let them trot up once more to see if the asymmetry would be consistent and then also maybe clinically relevant for the horse's health.

In conclusion, the app Sleip AI could give both the official veterinarians and the riders valuable information about the horses, when used as an aid at the horse inspection of FEI eventing competitions of the long format.

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References

Arkell, M., Archer, R.M., Guitian, F.J. & May, S.A. (2006). Evidence of bias affecting the interpretation of the results of local anaesthetic nerve blocks when assessing lameness in horses. *Veterinary Record*, 159 (11), 346–348

Barrey, E. (1999). Methods, applications and limitations of gait analysis in horses. *The Veterinary Journal*, 157 (1), 7–22

Baxter, G. M. & Stashak, T. S. (2020). Examination for lameness. *Adams and Stashak´s Lameness in Horses*. 7th ed. John Wiley & Sons, Inc

Bell, R.P., Reed, S.K., Schoonover, M.J., Whitfield, C.T., Yonezawa, Y., Maki, H., Pai, P.F. & Keegan, K.G. (2016). Associations of force plate and body-mounted inertial sensor measurements for identification of hind limb lameness in horses. *American Journal of Veterinary Research*, 77 (4), 337–345. https://doi.org/10.2460/ajvr.77.4.337

Bosch, S., Serra Bragança, F., Marin-Perianu, M., Marin-Perianu, R., Van der Zwaag, B.J., Voskamp, J., Back, W., Van Weeren, R. & Havinga, P. (2018). EquiMoves: A wireless networked inertial measurement system for objective examination of horse gait. *Sensors*, 18 (3), 850. https://doi.org/10.3390/s18030850

Bragança, F.S., Roepstorff, C., Rhodin, M., Pfau, T., Van Weeren, P.R. & Roepstorff, L. (2020). Quantitative lameness assessment in the horse based on upper body movement symmetry: The effect of different filtering techniques on the quantification of motion symmetry. *Biomedical Signal Processing and Control*, 57, 101674

Buchner, H.H.F., Savelberg, 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 (1), 71–76

Byström, A., Clayton, H.M., Hernlund, E., Rhodin, M. & Egenvall, A. (2020). Equestrian and biomechanical perspectives on laterality in the horse. *Comparative Exercise. Physiology*, 16, 35–45

Hardeman, A.M., Byström, A., Roepstorff, L., Swagemakers, J.H., van Weeren, P.R. & Serra Bragança, F.M. (2020). Range of motion and between-measurement variation of spinal kinematics in sound horses at trot on the straight line and on the lunge. *PloS One*, 15 (2), e0222822

Jansson, N. (1996). Equine osteoarthritis: A review of pathogenesis, diagnosis and treatment. *Pferdeheilkunde*, 12, 111–118

Kallerud, A.S., Fjordbakk, C.T., Hendrickson, E.H.S., Persson-Sjodin, E., Hammarberg, M., Rhodin, M. & Hernlund, E. (2021). Objectively measured movement asymmetry in yearling Standardbred trotters. *Equine Veterinary Journal*, 53 (3), 590–599. https://doi.org/10.1111/evj.13302

Keegan, K.G., Dent, E.V., Wilson, D.A., Janicek, J., Kramer, J., Lacarrubba, A., Walsh, D.M., Cassells, M.W., Esther, T.M. & Schiltz, P. (2010). Repeatability of subjective evaluation of lameness in horses. *Equine Veterinary Journal*, 42 (2), 92–97

Keegan, K.G., Kramer, J., Yonezawa, Y., Maki, H., Pai, P.F., 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

Kelmer, G., Keegan, K.G., Kramer, J., Wilson, D.A., Pai, F.P. & Singh, P. (2005). Computer-assisted kinematic evaluation of induced compensatory movements resembling lameness in horses trotting on a treadmill. *American Journal of Veterinary Research*, 66 (4), 646–655

Kramer, J., Keegan, K.G., Kelmer, G. & Wilson, D.A. (2004). Objective determination of pelvic movement during hind limb lameness by use of a signal decomposition method and pelvic height differences. *American Journal of Veterinary Research*, 65 (6), 741–747. https://doi.org/10.2460/ajvr.2004.65.741

Lopes, M.A.F., Eleuterio, A. & Mira, M.C. (2018). Objective detection and quantification of irregular gait with a portable inertial sensor-based system in horses during an endurance race—a preliminary assessment. *Journal of Equine Veterinary Science*, 70, 123–129. https://doi.org/10.1016/j.jevs.2018.08.008

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

Penell, J.C., Egenvall, A., Bonnett, B.N., Olson, P. & Pringle, J. (2005). Specific causes of morbidity among Swedish horses insured for veterinary care between 1997 and 2000. *Veterinary Record*, 157 (16), 470–477. https://doi.org/10.1136/vr.157.16.470

Persson Sjödin, E. (2020). *Evaluation of vertical movement asymmetries in riding horses: relevance to equine orthopaedics.* Diss. Uppsala: Sveriges lantbruksuniversitet. http://urn.kb.se/resolve?urn=urn:nbn:se:slu:epsilon-p-104570

Pfau, T., Parkes, R.S., Burden, E.R., Bell, N., Fairhurst, H. & Witte, T.H. (2016). Movement asymmetry in working polo horses. *Equine Veterinary Journal*, 48 (4), 517–522. https://doi.org/10.1111/evj.12467

Rhodin, M., Egenvall, A., Andersen, P.H. & Pfau, T. (2017). Head and pelvic movement asymmetries at trot in riding horses in training and perceived as free from lameness by the owner. *PloS One*, 12 (4). https://doi.org/10.1371/journal.pone.0176253

Rhodin, M., Persson-Sjodin, E., Egenvall, A., Serra Bragança, F.M., Pfau, T., Roepstorff, L., Weishaupt, M.A., Thomsen, M.H., van Weeren, P.R. & Hernlund, E. (2018).

Vertical movement symmetry of the withers in horses with induced forelimb and hindlimb lameness at trot. *Equine Veterinary Journal*, 50 (6), 818–824

Ringmark, S., Jansson, A., Lindholm, A., Hedenström, U. & Roepstorff, L. (2016). A 2.5 year study on health and locomotion symmetry in young Standardbred horses subjected to two levels of high intensity training distance. *Veterinary Journal*, 207, 99–104. https://doi.org/10.1016/j.tvjl.2015.10.052

Rogers, L.J. (1989). Laterality in animals. *International Journal of Comparative Psychology*, 3 (1)

Rogers, L.J. (2009). Hand and paw preferences in relation to the lateralized brain. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364 (1519), 943–954

Rogers, L.J. (2010). Relevance of brain and behavioural lateralization to animal welfare. *Applied Animal Behaviour Science*, 127 (1–2), 1–11

Ross, M.W. & Dyson, S.J. (2010). *Diagnosis and Management of Lameness in the Horse*. 2. ed. St. Louis: Elsevier.

Serra Bragança, F.M., Brommer, H., van den Belt, A.J.M., Maree, J.T.M., van Weeren, P.R. & Sloet van Oldruitenborgh-Oosterbaan, M.M. (2020). Subjective and objective evaluations of horses for fit-to-compete or unfit-to-compete judgement. *Veterinary Journal*, 257. https://doi.org/10.1016/j.tvjl.2020.105454

Starke, S.D. & Oosterlinck, M. (2019). Reliability of equine visual lameness classification as a function of expertise, lameness severity and rater confidence. *Veterinary Record*, 184 (2), 63–63

Uhlir, C., LICKA, T., Kübber, P., Peham, C., Scheidl, M. & Girtler, D. (1997). Compensatory movements of horses with a stance phase lameness. *Equine Veterinary Journal*, 29 (S23), 102–105

Van Heel, M.C.V., Kroekenstoel, A.M., Van Dierendonck, M.C., Van Weeren, P.R. & Back, W. (2006). Uneven feet in a foal may develop as a consequence of lateral grazing behaviour induced by conformational traits. *Equine Veterinary Journal*, 38 (7), 646–651

Van Weeren, P.R., Pfau, T., Rhodin, M., Roepstorff, L., Serra Bragança, F. & Weishaupt, M.A. (2017). Do we have to redefine lameness in the era of quantitative gait analysis? *Equine Veterinary Journal*, 4 9(5), 567-569. https://doi: 10.1111/evj.12715

Van Weeren, P.R., Pfau, T., Rhodin, M., Roepstorff, L., Serra Bragança, F. & Weishaupt, M.A. (2018). What is lameness and what (or who) is the gold standard to detect it? *Equine Veterinary Journal*, 50 (5), 549-551. http://doi: 10.1111/evj.12970

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), e0199447

Wang, Y., Li, J., Zhang, Y. & Sinnott, R.O. (2021). Identifying lameness in horses through deep learning. *SAC '21: Proceedings of the 36th Annual ACM Symposium on*

Applied Computing, Virtual Event Republic of Korea March 22 - 26, 2021. 976-985. https://doi.org/10.1145/3412841.3441973

Weishaupt, M.A., Hogg, H.P., Wiestner, T., Denoth, J., Stüssi, E. & Auer, J.A. (2002). Instrumented treadmill for measuring vertical ground reaction forces in horses. *American Journal of Veterinary Research*, 63 (4), 520–527

Williams, J. (2011). Laterality: implications for equine management and performance. *The Veterinary Nurse*, 2 (8), 434–441

Wrangberg, T. (2017). *Prevalensen av rörelseasymmetrier hos unga ridhästar*. (Avancerad nivå, A2E) Sveriges lantbruksuniversitet. Veterinärprogrammet. http://urn.kb.se/resolve?urn=urn:nbn:se:slu:epsilon-s-6347 [2021-06-07]

Zhou, H. & Hu, H. (2008). Human motion tracking for rehabilitation - A survey. *Biomedical Signal Processing and Control*, 3 (1), 1–18

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Popular science summary

Orthopaedic disorders are the most common reason for unplanned rest in the performing horse population. Locomotor disorders which slowly build up to clear lameness might be avoidable with easy access objective motion measurement devices. An early detection of a disorder affecting the locomotor apparatus will lead to an early diagnosis and directed treatment to avoid chronic, irreversible damages to the tissues, often caused by long drawn inflammation.

A decrease in performance will in most cases lead to a lameness examination to conclude if it is caused by pain. During the last 30 years, biomechanical researchers have established and refined sensitive objective measures of lameness. Unloading of a painful front- or hind limb leads to a vertical motion asymmetry of the head or pelvis respectively at the trot. These asymmetries can be detected with high precision and accuracy, but the relevance of small amplitude asymmetries is not fully elucidated and clear thresholds for where an asymmetry is likely to reflect a painful condition are lacking. Studies have proven that it is difficult for veterinarians to detect lameness classified as 1.5 and below (on the American scale of putting a degree of the lameness). This indicates that veterinarians could benefit from using an objective motion measurement device (OMD) as an aid.

Several studies have investigated the prevalence of motion asymmetries in different horse populations, revealing that asymmetries above clinically used thresholds are very common, ranging from 73-90% in mature riding horses, youngsters, endurance horses, standardbred trotters and polo horses. These high prevalence numbers and the sensitive measurement devices available have raised the question whether these asymmetries are caused by pain or if it is a question of biological variation of the gait pattern. In the search for the relevance of mild and moderate motion asymmetries, the relation to a high performing locomotor system is of particular interest. Therefore, studying horses that are judges to be “fit to compete” for high level events could provide insight.

The horses were filmed while being routinely shown at the horse inspection. Sleip AI was the OMD used in this study.

Sleip AI is an objective motion measurement device, a gait analysis system, that measures the horses’ movements and can detect if the horses in moving asymmetrically. This meaning shifting its weight to different limbs to avoid putting too much weight on a structure that might hurt. Sleip AI is a mobile phone application that uses artificial intelligence to analyse the movement of the head and the pelvis of the horse through a recorded video. The app then grades the asymmetries as non-asymmetrical, very mild asymmetry, mild, moderate and severe asymmetry. At a veterinary practice, sport horses these days that are investigated for a lameness are in many cases of the type mild and above.

In this study 58 horses were measured with Sleip AI at the first horse inspection and were included in the study after the rider had signed a consent form stating the data could be used. These horses’ data was then divided into groups whether they got a straight away “pass”, were sent to “holding” to trot up later once again for a new evaluation, “fail post holding” or “pass post holding”. 44 of these horses were before the last part of the competition (the showjumping) trotted up at the second horse inspection on the last day of the event.

The aim of this study was to investigate the vertical motion symmetry of Eventing horses during the horse inspection at a long format FEI competition. By describing the level of asymmetry in horses which were given a “pass” judgement by the FEI veterinarians we hoped to evaluate the usefulness of the objective gait analysis tool and to retrieve a range of values describing horses which are put in the holding box or for reinspection. By comparing asymmetries during the first, compared to the second horse inspection during this FEI event we wanted to investigate if the strenuous workload of the cross-country affected motion asymmetry of the horses on a group level. We also expected the study to give insight into the biological variation of vertical motion asymmetries in high performing riding horses and more specifically in this group of Eventers.

The results showed that 52% of the horses presented at the second horse inspection improved their total asymmetry (all asymmetries on all four legs put together as a total sum). 36% had a worsening/increased total asymmetry and 11% remained unchanged in their total asymmetry. But no significant difference on a population level was found (p =0.77) using a paired non-parametric test (Wilcoxon signed rank test).

Looking at the prevalence of asymmetry of the classification mild and above on the runs generating a “pass” during the first horse inspection only, it showed that 21/58 horses (36%) had an asymmetry on one leg or more, of mild type or more severe. In other studies with horses seen as sound by the owners, around 70% were asymmetrical above repeatability thresholds that are used to detect clinical lame-ness.

Compared to those groups of horses, this group of performing eventing horses at the event Pratoni del Vivaro long format 1*-4* level, might seem less asymmetrical. It is however difficult to compare between studies using different asymmetry measurement systems, since the signal processing differs between the tools. Also, the asymmetry threshold used in this study was set by the research team.

Looking at the total asymmetry, the horses that were sent to holding have a higher total asymmetry than the horses that were a straight away pass, but this was not tested statistically.

Some horses with a high degree of asymmetry slipped through the "pass" and here an OMD could have been a good aid. These horses' data is seen as extreme values (outliers) in the data here. When looking at some of these horses with an extreme value, one can see that many of them had an increase of the initial asymmetry on the same leg at the second horse inspection compared to the first. This might indicate that this specific asymmetry could be of relevance for the horses' health, and the information could be used to detect an orthopedic problem at an early stage.

Many of the outliers with a high degree of asymmetry were white/grey-coloured horses. When looking at the total asymmetry and the outliers in the "pass"-group at the first and second horse inspection, 3/5 and 3/3 horses were white coloured. This might indicate white horses are visually more difficult to assess.

Proper tests of agreement between the official veterinary staff and Sleip AI were not possible due to the low number of horses judged unfit to compete.