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DIPLOMA THESIS

SUBJECTIVE VERSUS OBJECTIVE LAMENESS INVESTIGATION

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1. Introduction

Lameness investigations play an important role in the profession of an equine veterinarian, as disorders of the locomotion system represent a major problem in horses and are often the reason for consulting a veterinarian. Although the fatality rate is quite low compared to other diseases, the financial burden of a lame horse being treated by a veterinarian and the lost time due to inability to train are undisputed (Seitzinger et al. 2000, Nielsen et al. 2014, Egenvall et al. 2008, Egenvall et al. 2013).

Working up a lame horse can be a difficult task. Especially mild lameness or hind limb lameness can be quiet challenging, even for experienced equine clinicians (Fuller et al. 2006, Arkell et al. 2006, Keegan et al. 2010, Keegan et al. 1998, Hammarberg et al. 2016, Leelamankong et al. 2020, Hewetson 2006, Peham et al. 1999, Peham et al. 2001).

Furthermore, the response to provocative tests or to diagnostic anesthesia can be difficult to assess or to quantify. This appears to be even more difficult when lameness is assessed through video analysis, compared to live lameness evaluations (Rungsri et al. 2014b, Armentrout et al. 2012).

Although, the influence of experiences on the correct assessment of gait is well documented, different studies show different results. While some investigations claiming that correctness of lameness evaluations rises with years of experience (Rungsri et al. 2014b, Starke and May 2017, Parkes et al. 2009) other studies find that experiences are not significantly influencing the outcome of lameness evaluations. Moreover, extended years of experiences can even have a potential negative influence on the accuracy of lameness evaluations as one tends to rely on a “feeling” (Starke and Oosterlinck 2019, Keegan 2019). Even experienced professionals are not free of the risk of being biased as it is only human to “see what one wants to see” (Keegan 2019, Arkell et al. 2006). It is therefore not surprising that different veterinary equine professionals reach different results when they examine the same horse for lameness (Keegan 2019, Arkell et al. 2006).

The human eye is only capable of capturing images with a frequency of 20 Hz, thus the ability to recognize asymmetries is limited. The inertial sensors of the system addressed in this literature review processes images at 200 Hz and are therefore more sensitive than the unaided eye (The Equinosis Q Lameness Locator® USA, User Manual 2019). The human eye needs approximately 25 % difference in amplitude between two moving objects to identify asymmetry as such (Parkes et al. 2009).

Therefore, tools for objective lameness assessments have been developed to improve and objectify lameness investigations worldwide. One in particular has been of great interest, as it has successfully made its way into clinical practice. The inertial sensor system (ISS) has not only convinced equine practitioners and horse owner with its easy and convenient handling, but above all with its reliable, repeatable and accurate measurements of gait asymmetry (Marshall et al. 2012, Keegan et al. 2002, Keegan et al. 2004, Keegan et al. 2011, Keegan 2007, Starke et al. 2012, Watanabe et al. 2011, Maliye et al. 2013, Moorman et al. 2013a, Moorman et al. 2013b).

Its non-invasive, field based measurements of movement asymmetry have been used to not only help detecting lameness and grade the severity of lameness, but also for before/after comparison of provocative tests, diagnostic anesthesia and any kind of therapy outcomes (Morgan et al. 2019, Marshall et al. 2012, Hoerdemann et al. 2017, Maliye et al. 2013, Moorman et al. 2019, Rettig et al. 2016, Keegan et al. 2013, Rungsri et al. 2014a, Rungsri et al. 2014b, Leelamankong et al. 2020).

1.1 Aim of the study

The aim of this literature review is to compare the results of an inertial sensor system in terms of gait analysis with the subjective assessment of lameness by equine veterinarians.

The advantages and disadvantages of both systems are to be explained and analyzed in detail in order to enable a target-oriented interpretation of the findings of the gait assessment.

Described findings are discussed to scrutinize the reliability of subjective lameness evaluation, to highlight the potential of objective lameness detection using an inertial sensor system and to compare these two systems to help optimize future lameness investigations.

1.2 Subjective lameness investigation

One of the subjective routine methods to evaluate lameness often used is the AAEP (American Association of Equine Practitioners) lameness scoring system, ranging from 0-5. The AAEP lameness scale aids in communication, but there is often a lack of agreement among different observers (Keegan et al. 2010).

The AAEP lameness score

0: Lameness not perceptible under any circumstances.

1: Lameness is difficult to observe and is not consistently apparent, regardless of circumstances (e.g. under saddle, circling, inclines, hard surface, etc.).

2: Lameness is difficult to observe at a walk or when trotting in a straight line but consistently apparent under certain circumstances (e.g. weight-carrying, circling, inclines, hard surface, etc.).

3: Lameness is consistently observable at a trot under all circumstances.

4: Lameness is obvious at a walk.

5: Lameness produces minimal weight bearing in motion and/or at rest or a complete inability to move.

https://aaep.org/horsehealth/lameness-exams-evaluating-lame-horse

The UK(United Kingdom) 0-10 lameness score

0 sound

1-3 mild lameness

4-6 moderate lameness

7-10 severe lameness

10 non-weight bearing lameness

https://www.vettimes.co.uk/app/uploads/wp-post-to-pdf-enhanced-cache/1/an-approach-to-diagnosing-lameness-in-equine-patients.pdf

The aim of an orthopedic examination is the detection and grading of gait asymmetry, if present, and further assessing the cause for this aberration (van Weeren et al. 2017).
When performing an orthopedic examination, usually conducted by an equine veterinarian, lameness assessment represents a crucial part of it. However, a complete orthopedic examination as it is taught to the students at the University of Veterinary Medicine of Vienna consists of other parts as well, such as: visual assessment of the locomotive system of the horse, e.g. the exterior, possible muscle atrophy, shoeing; or palpating the limbs. On one hand it definitely makes sense to palpate a horse's legs first *before* trotting it off, as one may find something that would indicate a certain increased risk for the horse when trotting it off. On the other hand, results from a physical examination can lead to bias, as one may expect a certain outcome based on the previous examination. A precise inquiry of the history of the horse forms an important part of an orthopedic examination and may alleviate work, however this can lead to bias too, as e.g. a history of previous trauma may or *may not* be the cause of the lameness presented. In conclusion, while all these tasks can help finding out the cause of the lameness, they can be misleading and therefore, must be critically scrutinized and the order in which they are executed must be chosen thoughtfully and individually.
The assessment of movement of the horse is usually done by walking the horse away and towards the observer followed by then trotting the horse in the same manner.
Lunging on soft or hard floor, an under-saddle investigation and others are possible and sometimes necessary (Dyson and Ross 2003, Peham et al. 2004, Davidson 2018, Dyson 2011).

An observed asymmetry in vertical motion of the head or pelvis between right and left limbs in trotting horses can be associated with pain, neurologic dysfunction or physical asymmetry between the limbs. This needs to be differentiated by the veterinarian through observation and palpation of the limbs and inquiring the history of the horse. If that is not enough, further procedures like diagnostic imaging or perineural anesthesia might be necessary (Keegan et al. 2013).

To get consistent results, the circumstances under which a horse is being presented should remain the same, especially the trotting speed needs to be comparable within trials (Dyson 2011).

There is possibly a high variability in the severity of lameness throughout the period of time the horses are trotted. Worsening of lameness can be due to increased strain (when trotting the horse several times on several consecutive days) and therefore an associated increase in pain, whereas an improvement of lameness can be due to over excitement masking the true state of pain (Rungsri et al. 2014a).

There are many other signs that need to be considered, e.g. movement of the limbs during the swing phase or the positioning of the hoof during the impact phase of the stance (Dyson 2014).

When the horse is lunged, it is expected to be quite symmetrical on both reins, though not pain-associated gait irregularities may exist. Therefore, the observer should be experienced with the gait assessment of sound horses (Dyson 2014).

When horses show a moderate to severe lameness clinicians agree whether or not a limb is lame most of the time, but when there is only mild lameness the agreement is poor. Therefore, especially with mild lameness the detection of asymmetry in gait lacks reliability (Keegan et al. 2010).

The difficulty of assessing hind limb lameness comparing to lameness in the forelimb is well documented in a study by Keegan et al. 2013. Veterinarians agree that a forelimb is lame about 3 out of 4 times while in hind limb lameness agreement occurred only in 2 out of 3 times (Keegan et al. 2013). When equine veterinarians were asked to pick the predominant lame limb of all 4 limbs, agreement among them was disappointingly low, as they agree less than 50 % of the time (Keegan et al. 2010). Moreover, in another study by Serra Bragança et al. 2020, FEI (Fédération Équestre Internationale) veterinarians had to judge whether a horse was fit to compete or not and their inter observer agreement was only fair (Serra Bragança et al. 2020).

There is no correlation between self-rated confidence in lameness assessment and actual performance on the task for forelimb and hind limb lameness (Starke and Oosterlinck, 2019).

Another influencing factor is whether or not the observers of the lameness were blinded.

In a study by Arkell et al 2006., the grade of lameness allocated by an observer to an individual horse when it was known it had been nerve-blocked was up to 4 times higher than when the horse was graded blindly (Arkell et al. 2006).

1.3 Objective measurements of lameness

Due to the previously pointed out downsides of subjective lameness evaluation, different types of objective gait analyzing tools have been invented over the past decades. A variety of devices to measure movement asymmetry or increased/decreased weight loading of the limbs have been designed. All these devices have been made in order to potentially ameliorate the accuracy and repeatability of lameness assessments.

1.3.1 Tools for gait analysis:

Kinetic techniques, such as a stationary force-plate, deliver highly sensitive and repeatable results, but they are time consuming and expensive and come with a reduced practicability.

Optical motion capture technologies, in which cameras record the 3D- position of markers placed on the horse’s skin overlying bony landmarks, have also gained major attention, since they are very accurate but they need to conduct their measurements in a dedicated calibrated space (Van Weeren et Gómez Álvarez, 2019, Serra Bragança et al. 2018).

1.3.2 Inertial sensor systems

Inertial sensor systems have been used in a wide range of applications in human medicine long before conquering the field of veterinary medicine. Not only in sports medicine and orthopedics, for example, to evaluate human movement parameters prior to surgery (Kluge et al. 2018) and after surgery (Van Dijk-Huisman et al. 2020, Jones et al. 2020, Bolink et al. 2015) , but also in neurology (Tunca et al. 2017, Schlachetzki et al. 2017, Ibrahim et al. 2020,) and traumatology (Howell et al. 2019) computerized motion analysis systems have been successfully applied.

ISS (Inertial sensor-systems) measure movement asymmetry between left and right halves of the stride, since all sound quadrupedal vertebrates are expected to exhibit bilateral movement symmetry within limb pairs (i.e. forelimb pair and hind limb pair) (Abourachid 2003).

A small degree of asymmetry during a horse´s gait is considered to be normal. Hence, it is not always necessary to assume a pathology as the cause of this asymmetry. In order to exclude this physiological asymmetry, which is not caused by pain, certain threshold values have been generated (Keegan et al. 2012, Keegan et al. 2013). However, in order to be able to tell with certainty that no pain is the cause of this asymmetry, regional anesthesia must be performed.

Inertial sensor systems (ISS) have been reported to detect lameness reliably and are easy to handle in a clinical setting (Keegan et al. 2002, Keegan et al. 2004, Keegan et al. 2011a, Keegan 2007, Starke et al. 2012 Watanabe et al. 2011, Maliye et al. 2013, Moorman et al. 2013a, Moorman et al. 2013b).

These inertial sensor systems are used to objectify pre-purchase examinations as well as for common lameness evaluations that include comparisons before and after flexion of the limb, for comparisons before and after diagnostic analgesia, or for comparisons before and after therapy of any kind of medication (Morgan et al. 2019, Marshall et al. 2012, Hoerdemann et al. 2017, Rungsri et al. 2014b, Maliye et al. 2013, Moorman et al. 2019, Rettig et al. 2016).

These inertial sensor based systems represent a noninvasive method and it does not interfere with the horse´s natural gait. The sensors are easy to attach to the horse’s body and collect data in real-time. Data are then analyzed rapidly using algorithms for detection of asymmetry and are highly accurate and repeatable (Marshall et al. 2012).

The sensor-based system of particular interest in this literature review (Equinosis Q Lameness Locator® USA) measures vertical acceleration of the torso to determine asymmetries in head and pelvic position between left and right halves of stride.

This ISS consists of three sensors: two accelerometers and one gyroscope. These sensors sample acceleration data at 200 Hz. The sensor on the head samples vertical head acceleration, the sensor on the pelvic tracks vertical pelvic acceleration.

The gyroscope is uni-axial and is placed on the right forelimb in the pastern region. This gyroscope measures angular velocity in the sagittal plane and determines right forelimb stance.

Based on the interpretation of the raw data, the software tells the customer not only the limb(s) affected, but also the severity of lameness using 5 grades (mild, mild to moderate, moderate, moderate to severe, severe), this suggests a comparison with the AAEP scoring system used by many clinicians. This kinematic gait analysis tells the painful phase of the stance (impact, mid-stance, push off) and how sure it is about the statement. (mild, moderate and severe evidence) based on the SD (Standard deviation) of the mean of measured differences in symmetry. A small SD would be indicative of a strong and repeatable asymmetry.

Data collected by the sensor-based system during gait analysis are: the mean difference in millimeters in maximum head height (HDMax), the mean difference in millimeters in minimum head height (HDMin), the vertical head measures (HMA), the pelvic movement asymmetry (PMA) and the the A1/A2 ratios.

Diff Max of the head represents the maximal height of the head before right front weight bearing minus (-) the max height of head before left front weight bearing. (The Equinosis Q Lameness Locator® USA, User Manual 2016).

Diff Min of the head represents the minimal height of head during right front mid-stance minus (-) the minimal height of head during left front mid-stance. Algorithms calculate head and pelvic height difference in millimeters between right and left halves of stride (The Equinosis Q Lameness Locator® USA, User Manual).

A Max Diff Head greater than +6.0 mm or less than -6mm is consistent with forelimb lameness.

Side and timing of forelimb lameness is dependent on the amplitude and sign of the *combined* Max Diff Head and Min Diff Head values.

A Max Diff Pelvis greater than +3.0 mm is consistent with a right hind limb push off lameness, less (more negative) than -3.0 mm is consistent with a left hind limb push off lameness.

A Min Diff Pelvis greater than +3.0 mm is consistent with a right hind limb impact lameness.

A Min Diff Pelvis less (more negative)than -3.0 mm is consistent with a left hind limb impact lameness (The Equinosis Q Lameness Locator® USA, User Manual).

The Lameness Locator distinguishes mid-stance from push-off and impact phase lameness.

Figure A: Possible changes in Diff Min Head/Diff Max Head

The positive value is indicating asymmetry of the right front, the negative value asymmetry of the left front (same for hind limb asymmetry)

A and B represent the Max Height of the head between left and right halves of the stride

C and D represent the Min Height of the head between left and right halves of the stride

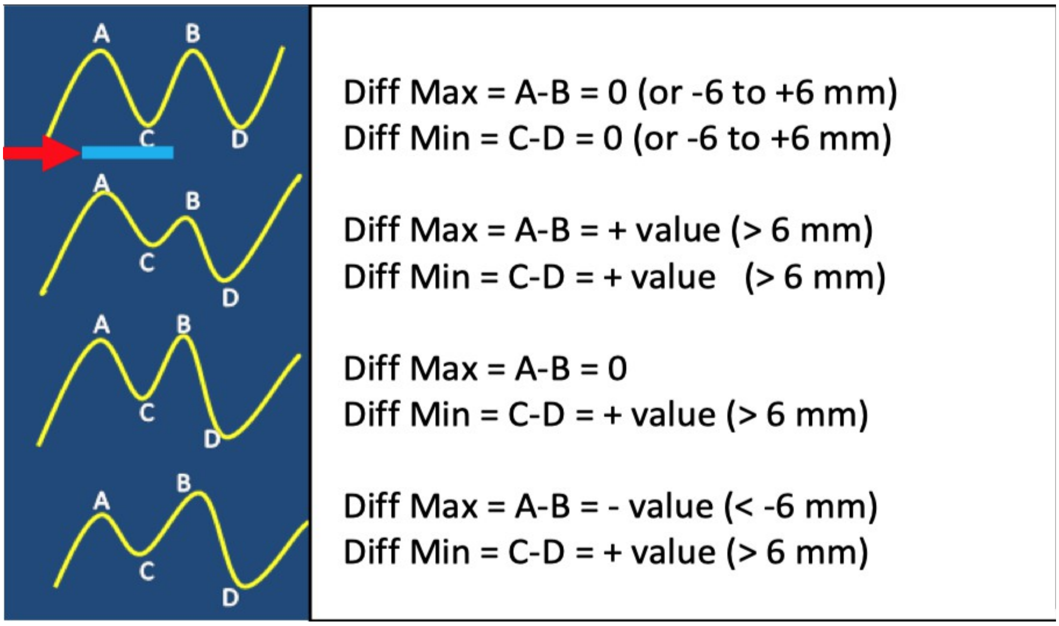
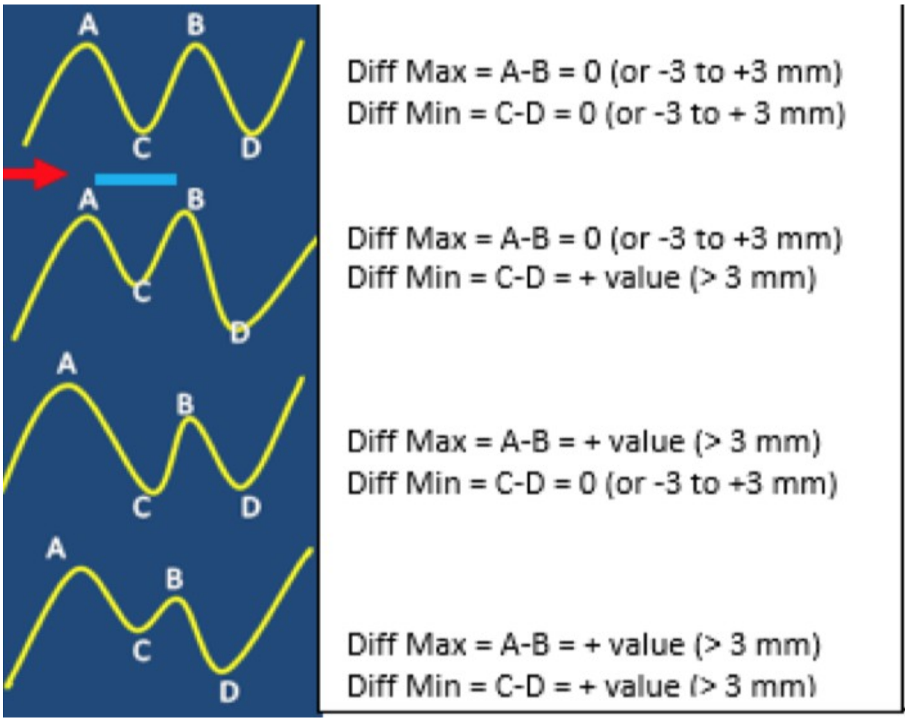


Figure B: Possible changes in Diff Min Pelvis/Diff Max Pelvis

A and B represent the Max Height of the pelvis between left and right halves of the stride

C and D represent the Min Height of the pelvis between left and right halves of the stride



A disadvantage of such an inertial sensor-based system that measures asymmetry between right and left limbs is the inability to reliably detect bilateral lameness of the fore limbs. For example, horses with equivalent lameness severity in right and left forelimbs during each stride would be determined to be sound, except when the lame forelimbs have a different kind of lameness, meaning one has a push off and the other an impact lameness.

For horses with bilateral lameness in which the severity of lameness is worse in one limb than it is in the contra lateral limb, the inertial sensor system would indicate unilateral lameness and therefore overshadow the pain in the less painful limb (Keegan et al. 2013). In case of bilateral lameness where one limb is lamer than the other, a positive reaction to diagnostic anesthesia may help outlining the true state of lameness, as the other (before lesser lame) limb may become the predominant lame limb.

However, bilateral lameness may be challenging to be evaluated subjectively as well (Dyson 2011).

Sometimes an under saddle investigation can be a quite challenging task for the inertial sensor system, as the rider may have an influence on the symmetry of the horse, although a study by Marqués et al. 2014 claims the experience of the rider is irrelevant when subjectively assessing the gait of a ridden horse. To determine the influence of the rider on the asymmetry of the gait of the horse, a sensor can be placed on the rider as well (Persson-Sjodin et al. 2018). Further research on the objectively measured movement asymmetry of horses when being ridden needs to be done (Marqués et al. 2014).

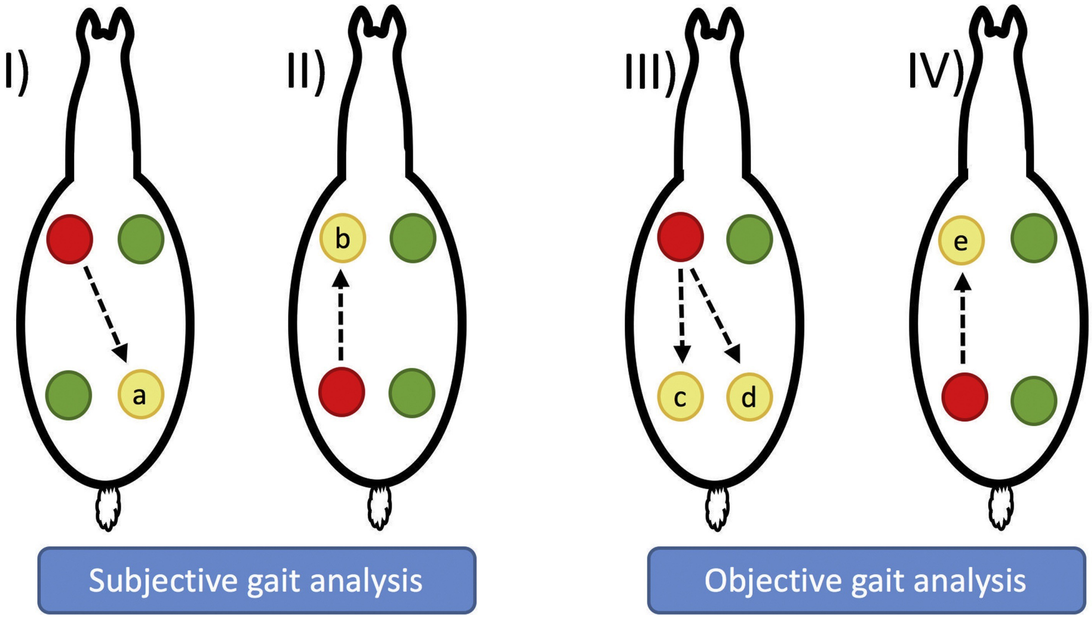


Figure C; Compensatory movements of the equine gait

Serra Bragança, F.M, Rhodin, M, and Van Weeren, P.R. "On the Brink of Daily Clinical Application of Objective Gait Analysis: What Evidence Do We Have so Far from Studies Using an Induced Lameness Model?" *The Veterinary Journal (1997)* 234 (2018): 11-23. Web

When evaluating a horse´s gait, compensatory movements of the head and/ or the pelvis can occur. Subjective observers may see compensatory contra lateral vertical displacement asymmetry of the pelvis (as seen in Fig. C graphic Nr. 1 ´a´) in horses primary lame in a forelimb (Figure C, graphic Nr. 1 red circle). In objective gait assessment a primary forelimb lameness (Fig. C graphic Nr. 3, red circle) is showing changes in asymmetry in both the ipsi- and the contralateral hind limb. (Figure C, graphic Nr. 3, ´c´ and ´d´, respectively)

As in horses with the hind limb being primary lame, observers (Fig. C graphic Nr. 2 red circle) and the objective measurement tool (Fig. C, graphic Nr. 4 red circle) see an ipsilateral compensatory vertical displacement asymmetry of the head. (Figur C, graphic Nr. 2 ´b´ and graphic Nr. 4 é´, (Serra Bragança et al. 2018).

In objective lameness evaluation, to discriminate compensatory asymmetries from primary movement asymmetries, a sensor attached to the withers has proven to be helpful. An increase in pelvic asymmetry in response to primary hind limb lameness achieved through induction, withers movement asymmetry increased towards the contra lateral side. When the forelimb was primary lame through induction, head movement asymmetry and withers movement asymmetry increased in the same direction (Rhodin et al. 2018). Newer sensor systems come with a withers sensor such as the EquiMoves (*EquiMoves* ® -www.*equimoves*.nl) or Equigait Ltd. (www.*equigait*.co.uk.) -objective lameness evaluation tool.

2. Materials and methods

2.1 Search strategy

A comprehensive literature search was accomplished using PubMed, Medline and Web of Science searching tools.
The keywords for the search were “gait analysis”, “Keegan” , “inertial sensor system” “lameness” “objective lameness” “subjective lameness”
Keegan was a keyword for the search as he is the inventor and founder of the Equinosis Q Lameness Locator®. Moreover, he published various studies testing the use of the Equinosis Q Lameness Locator®.

Inclusion criteria
Literature was included that either compares the subjective gait evaluation of horses to the gait analysis of an inertial sensor system as the main subject of interest, or provided both a subjective lameness scoring and the objective measurements data while going for another aim. Lameness could be induced or a natural occurring clinical problem. Horses could be lame in more than one limb. Subjective evaluation could have been done either live or through video analysis. Subjective evaluation can be done either by just one veterinarian or a group of veterinarians. Veterinarians can be of different levels of experience. Horses can be of different breeds and there was no age requirement/ restriction. Subjective and objective lameness examination can be consisting of just trotting in a straight line on hard surface or performing an extended lameness evaluation.
Objective gait analysis had to be performed with an inertial sensor system consisting of 2 accelerometers (one head and one pelvic) and an uni-axial gyroscope secured to the pastern region of the right forelimb (Equinosis Lameness Locator®). The subjective gait analysis could either be conducted using the AAEP (American Association of Equine Practitioners) Scoring System or other comparable scoring systems (e.g. a 0-10 scoring system mainly used

in the UK). Literature must be written in the English language and studies must be published before December 2020. In a final step, the selected literature must pass the QUADAS-Tool, meaning in this case, articles must be of mediocre or high quality. (See below)

Exclusion criteria

The use of an inertial sensor system that consists of other sensor positions than the ones previously mentioned.

2.3 Quality Assessment applying the QUADAS-Tool

QUADAS-Tool = Quality Assessment of Diagnostic Accuracy Studies

To ensure the publications discussed in this literature review are of a reasonable quality, the QUADAS-Tool was applied. This tool is an evidence based quality assessment scoring system consisting of 14 items phrased as questions. For each question, the study can either get one or zero points. One point for the answer "Yes" and 0 points for the answer "No" or the answer "unclear". 0-7 points represents a low quality study and 7-14 points a high quality study (Whiting et. al 2003).

The user´s guide to the QUADAS-Tool was used to ensure its correct application.
(BMC Medical Research Methology https://bmcmedresmethodol.biomedcentral.com/articles/10.1186/1471-2288-3-25 Access 17.05.2021)

The 14 Items of the QUADAS-TOOL.

1. Was the spectrum of patients representative of the patients who will receive the test in practice?
2. Were selection criteria clearly described?
3. Is the reference standard likely to correctly classify the target condition?

4. Is the time period between reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests?
5. Did the whole sample or a random selection of the sample, receive verification using a reference standard of diagnosis?
6. Did patients receive the same reference standard regardless of the index test result?
7. Was the reference standard independent of the index test (i.e. the index test did not form part of the reference standard)?
8. Was the execution of the index test described in sufficient detail to permit replication of the test?
9. Was the execution of the reference standard described in sufficient detail to permit its replication?
10. Were the index test results interpreted without knowledge of the results of the reference standard?
11. Were the reference standard results interpreted without knowledge of the results of the index test?
12. Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?
13. Were uninterpretable/ intermediate test results reported?
14. Were withdrawals from the study explained?

3. Results

3.1 List of selected studies

Six studies passed the inclusion criteria.

Table 1: List of selected studies

Reference	Study popula-tion	Main aim: subj vs. obj.?	Nat. occ. lame-ness	In-duced lame-ness	Nr. of obser-vers	Only experi-enced obser-vers	Only Fore-limb(s) lamenes s	Only Hind-limb(s) lamenes s	Fore-and hind-limbs	Lame-ness evalu-ation live	Video record-ings	Exten-ded proce-dures*	Blin -ded to the limb (s)
Lelamankong et al. 2020	26	Yes	Yes	No	13	No	No	Yes	No	Yes	Yes	Yes	Yes
Mccracken et al. 2012	15	Yes	No	Yes	13	Yes	No	No	Yes	Yes	No	No	Yes
Keegan et al. 2013	106	Yes	Yes	No	3	Yes	No	No	Yes	Ng	Ng	No	Ng
Marshall et al. 2012	17	No	Yes	No	1	Yes	No	Yes	No	Yes	No	No	Yes
Donnell et al. 2015	16	Yes	No	Yes	4	Yes	Yes	No	No	No	Yes	Yes	Partl y**
Rungsri et al. 2014b	24	Yes	Yes	No	13	No	Yes	No	No	Yes	Yes	Yes	Yes

* Extended procedures meaning e.g. diagnostic anesthesia, surgeries, drug application. Ng = not given

** Four clinicians evaluating lameness were blinded, one was not

Nat. occ. = Naturally occurring lameness

subj.= subjective

obj.= objective

1. Leelamankong, P., R. Estrada, K. Mählmann, C. Rungsri, and Lischer. "Agreement among Equine Veterinarians and between Equine Veterinarians and Inertial Sensor System during Clinical Examination of Hindlimb Lameness in Horses." *Equine Veterinary Journal* 52.2 (2020): 326-31. Web.

2. Mccracken, M., J. Kramer, K. Keegan, D. Lopes, S. Wilson, A. Reed, Lacarrubba, and Rasch. "Comparison of an Inertial Sensor System of Lameness Quantification with Subjective Lameness Evaluation." *Equine Veterinary Journal* 44.6 (2012): 652-656. Web.
3. Keegan, Kevin G, David A Wilson, Joanne Kramer, Shannon K Reed, Yoshiharu Yonezawa, Hiromitchi Maki, P Frank Pai, and Marco A F Lopes. "Comparison of a Body-mounted Inertial Sensor System-based Method with Subjective Evaluation for Detection of Lameness in Horses." *American Journal of Veterinary Research* 74.1 (2013): 17-24. Web.
4. Marshall, J. F., D. G. Lund, and L. C. Voute. "Use of a Wireless, Inertial Sensor-based System to Objectively Evaluate Flexion Tests in the Horse." *Equine Veterinary Journal* 44.43 (2012): 8-11. Web.
5. Donnell, J.R, D.D Frisbie, M.R King, L.R Goodrich, and K.K Haussler. "Comparison of Subjective Lameness Evaluation, Force Platforms and an Inertial-sensor System to Identify Mild Lameness in an Equine Osteoarthritis Model." *The Veterinary Journal* 206.2 (2015): 136-42. Web.
6. Rungsri, P., Staecker, W., Leelamankong, P., Estrada, R., Rettig, M., Klaus, C. and Lischer, C. (2014b) Agreement between a body-mounted inertial sensors system and subjective observational analysis when evaluating lameness degree and diagnostic analgesia response in horses with forelimb lameness. Pferdeheilkunde 30, 633–650

3.2 Results of the QUADAS-Tool

One out of six articles, Leelamankong et al. 2020, had mediocre quality, the other five articles were of high quality.

Table 2: Results of the QUADAS-Tool

		Leelamankong et al. 2020	Rungsri et al. 2014b	Donnell et al. 2015	Marshall et al. 2012	Keegan et al. 2013	McCracken et al. 2012
Item 1	Yes					1	
	No						
	Unclear	0	0	0	0		0
Item 2	Yes		1		1	1	1
	No						
	Unclear	0		0			
Item 3	Yes	1	1	1	1	1	1
	No						
	Unclear						
Item 4	Yes	1	1	1	1	1	1
	No						
	Unclear						
Item 5	Yes	1	1	1	1	1	1
	No						
	Unclear						
Item 6	Yes	1	1	1	1	1	1
	No						
	Unclear						
Item 7	Yes	1	1	1	1	1	1
	No						
	Unclear						
Item 8	Yes		1			1	1
	No	0		0			

	Unclear				0		
Item 9	Yes	1	1		1	1	1
	No			0			
	Unclear						
Item 10	Yes		1				
	No						
	Unclear	0		0	0	0	0
Item 11	Yes		1	1	1	1	
	No						
	Unclear	0					0
Item 12	Yes	1	1	1	1	1	1
	No						
	Unclear						
Item 13	Yes			1			1
	No		0		0	0	
	Unclear	0					
Item 14	Yes			1			1
	No		0		0	0	
	Unclear	0					
Summary		7/14	11/14	9/14	9/14	11/14	11/14
		Leelamankong et al. 2020	Rungsri et al. 2014b	Donnell et al. 2015	Marshall et al. 2012	Keegan et al. 2013	McCracken et al. 2012

The columns are the 14 items listed on page 17 and 18 . The rows are the six articles.

3.3 Results of the selected studies

The inertial sensor system had an overall greater sensitivity at detecting lameness than equine clinicians (Donnell et al. 2015, Rungsri et al. 2014b, McCracken et al. 2012). Agreement between the ISS and equine veterinarians rose with level of experience (Leelamankong et al. 2020, Rungsri et al. 2014b) and were higher when more severe lameness had to be evaluated (Leelamankong et al. 2020). Agreement between the ISS and practitioners was slightly better or the same (Rungsri et al. 2014b) when assessing the response to anesthesia compared to detecting base line lameness (Leelamankong et al. 2020, Rungsri et al. 2014b)

<u>Horses with only forelimb lameness</u>

In the study of Rungsri et al. 2014b, when detecting lameness, veterinarians were of different experience levels; when assessing the response to diagnostic anesthesia, only experienced veterinarians were consulted. Highly and moderately experienced clinicians had an overall moderate agreement with objective evaluation, with 67-82 % and 64-81 % agreement, respectively (Rungsri et al. 2014b). Inexperienced interns had only a fair agreement with objective evaluation, ranging from 45-77 %. The inertial sensor system is less likely to call a horse sound than clinicians (Rungsri et al. 2014b).

Highly experienced observers had an overall moderate agreement with the ISS regarding the response to diagnostic anaesthesia; in detail, three out of four observers had a moderate to strong agreement, and only one had a weak agreement (Rungsri et al. 2014b.

In the study by Donnell et al. 2015, the detection of forelimb lameness was performed by not only experienced clinicians and an ISS, but also by a stationary force plate. Lameness was induced by creating an unilateral carpal osteochondral fragment (OCF) in the middle carpal joint . The agreement on which forelimb was lame was conducted at several time points. The inertial sensor system identified the highest percentage of horses as lame in the OCF limb (60 %), followed by the blinded subjective evaluation (54 %). The force plate identified 40 % of horses lame in the OCD limb. The agreement was greatest between the subjective evaluators and the inertial sensor system, although their agreement was only fair to poor (50-60 %) (Donnell et al. 2015).

<u>Horses with only hind limb lameness</u>

In the study by Leelamankong et al. 2020, mild to moderate lameness (grades 1-3 of the AAEP lameness scoring system) was evaluated by veterinarians of different levels of experience. The response to diagnostic anesthesia was determined by only highly experienced clinicians. Through video analysis, there is a fair agreement between the ISS and the highly experienced subjective observers regarding the detection of hind limb lameness, a slight to fair agreement in the group with moderate experience, and a slight agreement in the inexperienced group. When detecting lameness live, highly experienced veterinarians had a moderate agreement with the ISS (Leelamankong et al. 2020). Agreement between objective and subjective evaluation was generally higher for more severe lameness in each experience group.

When assessing the response to diagnostic anesthesia, three out of four highly experienced individuals had a positive and strong agreement with the ISS, the fourth one however had a positive but weak agreement (Leelamankong et al. 2020). Inter-observer agreement of clinicians in a clinical situation showed a “moderate” agreement, while the clinicians of all experience levels who assessed the lameness through video analysis had only a “fair” agreement (Leelamankong et al. 2020).

One study by Marshall et al. 2012 evaluated the response to flexion tests.. A positive response, as assessed subjectively, led to a significant increase in PMA (pelvic movement asymmetry) and PDMax (Difference in maximum pelvic height), but not in PDMin (Difference in minimum pelvic height). PDMin was not significantly altered (Marshall et al. 2012).

<u>Horses with both fore- and hind limb lameness</u>

In the study by McCracken et al. 2012 lameness was induced via sole pressure. The sensitivity for the detection of lameness was determined. The ISS detected the lame limb earlier, meaning at a significantly lower level of sole pressure, than the experienced veterinarians. The inertial sensor system selected the correct limb before the three veterinarians in 58.33 %, the evaluators selected the correct limb before the inertial sensors in 8.33 %, and in 33.33 % they selected the correct limb at the same time (McCracken et al. 2012).

A similar study by Keegan et al. 2013 compared the detection of lameness with an ISS to the detection of lameness by experienced equine practitioners.

The agreement between the ISS and the clinicians was fair to moderate (58.8 %) for forelimb lameness and slight to fair (54.7 %) for hind limb lameness (Keegan et al. 2013). Correlations and agreements between inertial sensor system measures of lameness, and results of subjective lameness evaluations were statistically significant but not strong.

Differences in maximum pelvic height had the highest correlation with subjective results. Differences in minimum pelvic height did not have such a strong correlation with subjective observation (Keegan et al 2013).

4. Discussion

The higher sensitivity of the objective (ISS) compared to the subjective gait assessment in the study of McCracken et al. 2012 and in the study of Rungsri et al. 2014b could be because the lameness was only mild, and mild lameness is more difficult to detect (Keegan et al. 2010, Leelamankong et al. 2020). In the study of McCracken et al. 2012 lameness was induced in both fore and hind limbs and the task of assessing hind limb lameness can be challenging (Keegan et al. 2010, Starke and Oosterlinck 2019). This statement is supported by Keegan et al. 2013, where the agreement between the ISS and equine clinicians was better for forelimb lameness than for hind limb lameness.

However, these results of the study of McCracken et al. 2012 are still disappointing, as the clinicians were aware that lameness was induced, lameness evaluation was performed live and the veterinarians were highly experienced. All these factors could have led to a higher sensitivity, (Armentrout et al. 2012, Arkell et al. 2006, Donnell et al. 2015, Keegan et al 2010, Fuller et al. 2006, Rungsri et al. 2014b.) although some state experience does not improve the quality of the lameness analysis (Starke and Oosterlinck 2019, Keegan 2019).

The challenge of video analysis could also explain the moderate agreement in live clinical examinations in the study by Leelamankong et al. 2020 contrary to the only fair (Leelamankong et al. 2020) and fair to poor agreement (Donnell et al. 2015) through video analysis. Lameness through video analysis is challenging because the gait of the horse can only be evaluated from the front and back, whereas the step length, the push off phase and the arc of the foot during the flight can not or at least not as easily be assessed as when the horse is viewed from the side (Dyson 2014). The lack of an audio makes it impossible to evaluate factors like the loudness of the footfall or the rhythm or toe dragging (Davidson 2018).

However, the fair to poor agreement (Donnell et al. 2015) might still be surprising as only forelimb lameness was evaluated and only highly experienced clinicians were asked to evaluate the lameness.

Moreover, why did the ISS identify the highest percentage of horses as lame in the OCF limb, but still only 60 %? In this study, bilateral lameness cannot be excluded, as even before lameness induction blinded subjective evaluation judged 31 % of horses as lame, and the ISS found a lameness in as many as 75 % of horses. Non-blinded subjective evaluation judged 50 % of the horses as lame before actual induction of lameness. The possible presence of bilateral lameness could also be the reason for the modest 54 % of horses judged lame in the lameness induced limb by blinded subjective evaluation. When the limb of the baseline lameness (meaning lameness before induction) was the same limb as the later OCF limb, detection of lameness by the ISS in the induced limb was around 80 %, whereas if lameness was identified at baseline in the limb contra lateral to the OCF limb, the ISS identified only 13 % of horses lame in the induced limb.

Therefore, a gold standard for the detection of the “correct” limb as the lame limb could not be determined (Donnell et al. 2015).

The moderate agreement between the ISS and subjective observers in the study of Rungsri et al. 2014b regarding the response to diagnostic anaesthesia could be due to the fact that only highly experienced veterinarians participated in the trial, (Starke and May 2017, Parkes et al. 2009) or because only forelimb lameness was assessed. (Keegan et al. 2013)

The stronger agreement between the ISS and the clinicians when assessing the response to diagnostic anesthesia in comparison to assessing baseline lameness in the study of Rungsri et al. 2014b and Leelamankong et al. 2020 may be explained by the fact that both studies only used veterinarians of high experience at this specific part of the lameness examination.

The study by Marshall et al. 2012 performing flexion tests found a significant increase in PMA and PDMax only. This is supported by the study of Keegan et al. 2013, that claims that differences in maximum pelvic height between left and right halves of the stride had the highest correlation with subjective results on classification on hind limb lameness in horses. PDMin was not significantly altered in the study by Marshall et al., indicating that when assessing hind limb lameness, one recognizes the lame hind limb as lame through the upward movement of the pelvis, not the downward movement (Keegan et al. 2013).

In the study of Leelamankong et al. 2020 and in the study of Rungsri et al.2014b agreement in evaluating the response to diagnostic anesthesia between the ISS and 3 of the 4 highly experienced observers was moderate (Rungsri et al. 2014b) and strong (Leelamankong et al. 2020).

However in both studies, at least one highly experienced clinician only had a weak agreement with the ISS (Leelamankong et al. 2020, Rungsri et al. 2014b).

What is the reason for one of the four observers to be so out of line?

One possible reason is the influence of the trotting speed on the movement symmetry and the circle radius, as it may not be the clinician´s preference and therefore complicate the assessment (Starke et al. 2013, Peham et al. 2000, Pfau et al. 2012). Trotting at very high speeds, 3,61 $m\,s^{-1}$ and 4,76 $m\,s^{-1}$, for straight line and circle respectively (Starke et al. 2013) or slow (Dyson 2011) may mask the true state of lameness. This statement by Starke et al. 2013 is opposed to a study by Peham et al. 2000, as trotting at very high speed accentuated moderate forelimb lameness significantly but reduces the amplitude of the head motion, therefore subjective lameness evaluation of veterinarians at high trotting speed is very difficult (Peham et al. 2000, Starke et al. 2013).

The use of different lameness scoring systems (AAEP, UK System) can aggravate the comparability and therefore influence the results. If no half grades were permitted in the AAEP lameness scoring, the comparability to the UK system is not given. Moreover, not being used to the lameness scoring system imposed on oneself when assessing lameness may be an additional challenge for the veterinarian.

As multi limb lameness is quite common in a realistic lameness evaluation, this needs to be kept in mind in the studies evaluating only one lame limb (Morgan et al. 2019, Hoerdemann et al. 2017, Donnell et al. 2015, Schumacher et al. 2013, Rungsri et al. 2014b).

In the study of Keegan et al. 2013 the agreement between the ISS and the veterinarians was only fair to moderate for forelimb lameness and slight to fair for hind limb lameness. Can only the fact that hind limb lameness was evaluated as well lead to such poor agreement? At first, these results are surprising, as only experienced clinicians assessed the lameness and these clinicians only had to assess the lameness into three lameness categories (right>left, left>right, equal). At a closer look, full lameness evaluation was done, including flexion test and lunging in a circle. The length of the lameness examination could have confused the veterinarians and led to a different rating. (Keegan et al. 2010) Moreover only three veterinarians evaluated the lameness, which is quite a small number for a statistically expressive result.

5. Conclusion

Routine subjective lameness examination in horses can be a challenging task, hampered by bias and expectations. These subjective influences are difficult to suppress in everyday life, therefore a combination of subjective lameness detection with objective gait analysis has proven to be the most accurate and reliable and therefore best solution for the horse, the owner, and the treating veterinarian.

6. Limitations

The restricted amount of papers, especially of those addressing the main aim of comparison between objective and subjective lameness analyses definitely were a limiting factor.

7. Abstract

Background:
The subjective evaluation of lameness in horses lacks reliability and accuracy, as it is influenced by factors, such as bias and expectations. Several computerized objective gait analysis systems have been developed. The Equinosis Lameness Locator®, USA, amongst others, is an objective lameness evaluation system that is in clinical use since many years for lameness examinations as well as for teaching students how to assess lameness in horses.

Study design:
Literature review

Aim of this study:
The aim of this literature review is to compare the results of an inertial sensor system in terms of gait analysis with the subjective assessment of lameness by equine veterinarians.

Main Results:
The inertial sensor system had an overall greater sensitivity at detecting lameness than equine clinicians (Donnell et al. 2015, Rungsri et al. 2014b, McCracken et al. 2012). Agreement between the ISS (Inertial sensor-system) and equine veterinarians rose with level of experience (Leelamankong et al. 2020, Rungsri et al. 2014b) and for more severe lameness (Leelamankong et al. 2020). Agreement between the ISS and practitioners was slightly better or the same (Rungsri et al. 2014b) when assessing the response to anesthesia compared to detecting base line lameness (Leelamankong et al. 2020, Rungsri et al. 2014b).

Conclusion:
A combination of subjective lameness detection with objective gait analysis has proven to be the most accurate and reliable and therefore best solution for all parties involved.

Keywords: gait analysis, lameness, inertial sensor system, subjective, objective

8. Deutsche Zusammenfassung

Hintergrund:
Lahmheit stellt ein häufig vorkommendes Problem bei Pferden dar, das teilweise mit hohen tierärztlichen Kosten verbunden sein kann. Die Ursache des Schmerzes, der damit für das Pferd verbunden ist, muss in den meisten Fällen von einem Tierarzt abgeklärt werden. Tierärztliche Lahmheitsuntersuchungen bestehen vor allem aus der Beurteilung des Gangbildes in Bewegung. Die subjektive Beurteilung von Lahmheiten kann aber sehr unterschiedlich ausfallen, was einen Schwachpunkt in der Lahmheitsuntersuchung darstellt. Nicht nur das menschliche Auge, das durchschnittlich nur 20, jedoch maximal 50-60 Bilder pro Sekunde wahrnehmen kann, sondern auch Einflüsse wie Erwartungshaltung und Erfahrung stellen kaum beeinflussbare, limitierende Faktoren dar. Durch diese Problematik entstand das Interesse, Lahmheitsuntersuchungen zu objektivieren. Im Laufe der letzten Jahrzehnte wurden mehrere Instrumente zur objektiven Gangbildanalyse auf den Markt gebracht. Aufgrund seiner leichten Handhabung und der Genauigkeit der Messwerte hat sich besonders ein Trägheitssensor-Systeme bewährt, der Equinosis Q Lameness Locator® USA.

Art der wissenschaftlichen Arbeit:
Literaturzusammenfassung

Ziel der Studie:
In dieser Literaturzusammenfassung wurde die subjektive Lahmheitsuntersuchung des Tierarztes mit der objektiven Gangbildanalyse des Equinosis Q Lameness Locator® verglichen.

Ergebnisse:
Das Trägheitssensor-System bewies sich als sensitiver beim Erkennen einer Lahmheit als das menschliche Auge. Die Übereinstimmung zwischen subjektiver und objektiver Beurteilung der Lahmheit steigt mit der Berufserfahrung der Tierärzte. Die Übereinstimmung steigt ebenfalls, je stärker die Lahmheit vorhanden war.

Schlussfolgerung:
Um das bestmöglichste Ergebnis für Pferd, Besitzer und Tierarzt zu erreichen, besteht die optimale Lahmheitsuntersuchung sowohl aus subjektiver als auch aus objektiver Beurteilung des Gangbildes.

9. Abbreviation register

AAEP = American Association of Equine Practitioners

HDMax =Maximum in head height

HDMin = Minimum in head height

ISS = Inertial sensor-system

Nat. occ. = Naturally occurring

Nr. = Number

obj.= objective

OCF= osteochondral fragment

PDMax = Difference in maximum pelvic height

PDMin = Difference in minimum pelvic height

PMA = Pelvic movement asymmetry

subj.= subjective

UK = United Kingdom

SD = Standard deviation

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11. List of figures and tables