Comparison of an inertial sensor system of lameness quantification with subjective lameness evaluation

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Summary

Reasons for performing study: Subjective evaluation of mild lameness has been shown to have poor interobserver reliability. Traditional methods of objective lameness evaluation require specialised conditions and equipment. Wireless inertial sensor systems have been developed to allow for simple, rapid, objective lameness detection in horses trotted over ground.

Objective: The purpose of this study was to compare the sensitivities of an inertial sensor system and subjective evaluation performed by experienced equine practitioners at detecting lameness in horses. We hypothesised that the inertial sensor system would identify lameness at a lower level of sole pressure than a consensus of 3 experienced equine veterinarians.

Methods: Fifteen horses were fitted with special shoes that allowed for lameness induction via sole pressure. Horses were simultaneously evaluated by 3 equine veterinarians and a wireless inertial sensor system. Horses were subjected to multiple trials: 1) before inserting the screw; 2) after inserting the screw to just touch the sole; and 3) after tightening the screw in half turn increments. The number of screw turns required for lameness identification in the correct limb by the inertial sensors and by consensus of 3 equine veterinarians was compared using the Wilcoxon test.

Results: The inertial sensor system selected the limb with the induced lameness after fewer screw turns than did the 3 veterinarians (P<0.0001). The inertial sensor system selected the correct limb before the 3 veterinarians in 35 trials (58.33%), the evaluators selected the correct limb before the inertial sensors in 5 trials (8.33%), and in 20 trials (33.33%) they selected the correct limb at the same time.

Potential relevance: The inertial sensor system was able to identify lameness at a lower level of sole pressure than the consensus of 3 equine veterinarians. The inertial sensor system may be an effective aid to lameness localisation in clinical cases.

Keywords: horse; lameness; inertial sensor; biomechanics; sports medicine

Introduction

Lameness is an important medical problem in horses that not only results in discomfort for the horse but also results in significant economic loss to horse owners and professionals [1]. A subjective lameness evaluation by a trained equine veterinarian is the standard for lameness diagnosis. However, studies have shown that subjective evaluation of lameness, especially when mild, is not reliable [2–5]. It has also been demonstrated that evaluators can be biased towards judging improvement in lameness after diagnostic blocking [3]. Low reliability and bias adversely affect timely and accurate identification and localisation of lameness, which negatively affects successful treatment.

As an aid to subjective evaluation, kinetic and kinematic techniques that objectively identify and quantify lameness have been developed. Both techniques rely on and use biomechanical principles known to be associated with lameness. Kinetic techniques typically involve measuring ground reaction forces on the limbs during the stance phase of the stride, using a stationary force plate, specially designed force-measuring shoes, or a specially designed force-measuring treadmill [6–10]. Kinematic evaluations typically involve 3D motion analysis of the head, torso and limbs captured by multiple high-speed cameras [11–14]. Both kinetic and kinematic analyses provide precise and accurate identification and quantification of lameness. However, these methods require expensive equipment and time commitments. They are generally not practical for a clinical setting.

Recently developed wireless inertial sensor systems provide a means for objective evaluation of multiple strides of lameness as the horse moves over ground [15,16]. These systems have the potential for easy and practical clinical application as they enable simultaneous subjective evaluation by an examiner and data collection and analysis as the horse is trotted over ground. The purpose of this study was to evaluate one such wireless inertial sensor system [Lameness Locator®] of lameness quantification by comparing it to simultaneous subjective evaluation by experienced equine practitioners, using an induced sole-pressure lameness model [7,8,11,12,17]. Specifically we wanted to compare the inertial sensor system’s sensitivity for detecting lameness with simultaneous subjective evaluation. It was hypothesised that the inertial sensor system would identify lameness at a lower level of sole pressure than a consensus of 3 experienced equine veterinarians.

Material and methods

Horses

Fifteen mature horses (age range 2–22 years, mean 7 years) from the University of Missouri herd were used in this study, consisting of 12 Quarter Horses, one Thoroughbred, one American Saddlebred and one pony. All horses trotted naturally on a lead shank and no horse had consistently detectable lameness in a straight line.

Lameness induction

All horses were shod on all 4 feet with a specially designed shoe that could, when activated, induce a temporary lameness (Fig 1). The shoes were constructed with a wide crossbar running between medial and lateral quarters and an additional centre bar running from this crossbar to the toe of the shoe. Threaded 1 cm diameter holes were machined into the crossbar adjacent to the junction of crossbar and branches (medial and lateral) of the shoe and in the centre bar adjacent to the junction with the toe of the shoe. The shoes could be activated to induce progressively increasing sole pressure and temporary lameness by inserting 1 cm diameter flat-headed screws into the threaded holes and tightening. Lameness resolved after removing the screws. This lameness model and study design was approved by the Institutional Animal Care and Use Committee of the University of Missouri.

Inertial sensor system

Objective lameness analyses were performed using a body-mounted inertial sensor system. Horses were instrumented with a uni-axial (vertical)
6 g (1 g = 9.8 m/s²) accelerometer sensor on the head and dorsum of the pelvis and a uni-axial gyroscopic sensor on the dorsal surface of the right forelimb pastern (Fig 2). The head accelerometer sensor was attached to a short strip of adhesive 3M Dual Lock tape sewn to a felt hat with cutouts for the ears, which was worn by the horse and attached to the halter with Velcro tabs. This positioned the sensor just behind the ears at the poll on midline. The pelvic accelerometer sensor was attached to a short strip of 3M Dual Lock tape placed between the tubera sacrale and additionally secured with duct tape. The right forelimb gyroscope sensor was placed in a specially designed pastern wrap. Each sensor consisted of a microelectrical-mechanical device (accelerometer or gyroscope), radio, antennae, battery, microcontroller, and associated circuitry for wireless transmission of data (3 channels synchronously sampled at 200 Hz).

**Inertial sensor measures**

Data obtained by the 3 sensors were transmitted using wireless technology in real time to a portable computer where a specially designed set of algorithms based on a fault detection approach quantified the perturbation of normal symmetrical head and pelvic vertical movement associated with lameness [13]. Lameness severity and affected limb were reported as the following variables: a1/a2 – amplitude of the vertical head or pelvic movement due to lameness divided by the amplitude of the expected, normal vertical movement of the head or pelvis; mindiff – difference between the minimum heights of the head during the stance of the right and left forelimbs or the minimum heights of the pelvis during the stance of the right and left hindlimbs; and maxdiff – difference between the maximum heights of the head after the stance of the right and left forelimbs or the maximum heights of the pelvis after the stance of the right and left hindlimbs.

**Subjective evaluation protocol**

During each lameness induction period, the horses were simultaneously evaluated by 3 experienced equine practitioners. Evaluators were blinded to the limb, the location of the screw (toe/heel) and the other evaluators’ results. However, evaluators were not blinded to the study protocol, i.e. they were aware that a progressively worsening lameness was being induced. Evaluators were not allowed to evaluate all 4 lameness inductions for a particular horse. This was to ensure that the veterinarians conducting the subjective evaluation would not, using memory of preceding lameness inductions on a horse, successfully narrow down the limb involved by
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for head movement for forelimb lameness; 0.17 for pelvic movement for when the conditions were met for both collections per trial. The 3 lameness was considered to be detected by the inertial sensor system only evaluators were required only to make one selection per trial. However, lameness was considered to be detected by the inertial sensor system only when the conditions were met for both collections per trial. The 3 conditions necessary for identification of lameness by the wireless inertial sensor system were: 1) the a1/a2 ratio had to be above threshold (0.5 for head movement for forelimb lameness; 0.17 for pelvic movement for hindlimb lameness); 2) the mean mindiff head and/or maxdiff head (for forelimb lameness) and mindiff pelvis and/or maxdiff pelvis (for hindlimb lameness) were above threshold (±0.6 mm for forelimb lameness; ±3 mm for hindlimb lameness) and of the correct sign (positive or negative) depending on the limb (right or left) selected for lameness induction; and 3) the standard deviation of the elevated mindiff or maxdiff or both for the head or pelvis had to be less than the absolute value of their respective means [15,17,18]. This last condition demanded consistency in lameness throughput each trial.

Data analysis

The outcome variable was the number of half turns of the screw required for detectable lameness. The effect of subjective vs. wireless inertial sensor system evaluation on the number of half turns was compared with the Wilcoxon signed-rank’s test. The proportion of trials where the subjective evaluators identified the lameness first, the wireless inertial sensor system identified the lameness first, or the subjective evaluators and the wireless inertial sensor system identified the lameness at the same time was compared to expected chance with a Chi-square test. The effect of limb (fore- vs. hindlimb) and location (toe vs. heel) on the subjective vs. wireless inertial sensor system was assessed with Fisher’s exact test. Significance was set at P≤0.05.

Fig 3: Placement of a flat 1 cm diameter screw in the toe position and tightened until it is just touching the sole.

Simple elimination. A total of 13 experienced equine practitioners provided evaluations for this study. The evaluators were exclusively equine practitioners who routinely conducted equine lameness examinations.

Four of the evaluators were board certified with the American College of Veterinary Surgeons and the others were equine-exclusive practitioners.

The weighted mean years-of-experience per evaluation was 17.

Study design

The horses were fitted with the special shoes on all 4 feet. During 4 separate evaluation periods, each horse was subjected to temporary lameness by insertion and tightening of the flat screw in the shoe of only one limb. Using a crossover design, 4 episodes of lameness were induced in each horse: forelimb toe, forelimb heel, hindlimb toe and hindlimb heel for a total of 60 lameness inductions. Immediately before each trial, the limb and region of the foot to be subjected to pressure were randomly assigned by drawing out of a hat. The interval between the induced lameness episodes for each horse was at least 24 h. A baseline evaluation was conducted prior to each lameness induction. If the horse was observed to be lame from a previous induction, then a new lameness induction was not carried out.

During each lameness induction period, the horse was simultaneously evaluated by 3 experienced equine practitioners and by the wireless inertial sensor system. Each trial started with a baseline evaluation performed before inserting the screw in the shoe. For each lameness evaluation, the horse was trotted back and forth on a 30 m concrete runway for a total distance of 120 m. This was repeated for a second evaluation. Thus, there were 2 inertial sensor collections per trial. The screw was then inserted into the shoe and hole of the selected limb and location and then tightened to a depth such that it was just touching the sole (Fig 3). A lameness trial was then conducted. The horse was trotted back and forth on a 30 m concrete runway for a total distance of 120 m. This was repeated for a second evaluation. Successive additional trials were then conducted in which the screw was sequentially tightened an additional half turn. Successive additional trials were repeated until lameness of the selected limb had been detected by the 3 evaluators and by the inertial sensor system. Thus the degree of sole pressure and corresponding lameness gradually increased throughout the lameness induction.

Lameness was considered to be detected by the 3 evaluators when they all selected the correct limb in which lameness was being induced. The evaluators were required only to make one selection per trial. However, lameness was considered to be detected by the inertial sensor system only when the conditions were met for both collections per trial. The 3 conditions necessary for identification of lameness by the wireless inertial sensor system were: 1) the a1/a2 ratio had to be above threshold (0.5 for head movement for forelimb lameness; 0.17 for pelvic movement for hindlimb lameness); 2) the mean mindiff head and/or maxdiff head (for fore- vs. hindlimb) and mindiff pelvis and/or maxdiff pelvis (for hindlimb lameness) were above threshold (±0.6 mm for forelimb lameness; ±3 mm for hindlimb lameness) and of the correct sign (positive or negative) depending on the limb (right or left) selected for lameness induction; and 3) the standard deviation of the elevated mindiff or maxdiff or both for the head or pelvis had to be less than the absolute value of their respective means [15,17,18]. This last condition demanded consistency in lameness throughout each trial.

Results

Overall

A total of 60 trials were performed on 15 horses. There were a total of 30 trials of forelimb lameness and 30 trials of hindlimb lameness. All trials were included in the analysis. None of the horses were eliminated after the baseline trial because of persistent lameness from a previous induction. In one lameness induction, neither the equine veterinary evaluators nor the wireless inertial sensor identified the limb with induced lameness before no further additional sole pressure could be induced. This lameness induction was considered a tie.

The inertial sensor system selected the limb with the induced lameness sooner (i.e. after fewer half turns of the screw) than the consensus of 3 subjective evaluators (P<0.001). The inertial sensor system identified the limb with the induced lameness after a median of 5 half turns (range 1–11) and subjective consensus of 3 veterinarians identified the limb with the induced lameness after a median of 6 half turns (range 2–13).

Subjective consensus of 3 veterinarians selected the limb with induced lameness before the inertial sensor system in 5 of 60 (8.3%) trials. The inertial sensor system identified the limb with induced lameness before the evaluators in 35 out of 60 (58.3%) lameness inductions. The evaluators and the inertial sensors identified the limb with induced lameness at the same time in 15 of 60 (33.3%) lameness inductions. The proportion of lameness inductions picked correctly first by the evaluators was less than expected by chance and significantly less than the proportion of lameness inductions picked correctly first by the inertial sensor system (P<0.001). The proportion of lameness inductions in which the evaluators and the inertial sensor system detected lameness at the same time was equivalent to what would be expected by chance, but this was significantly less than the proportion of lameness inductions picked correctly first by the inertial sensor system (P<0.025).

Fores- vs. hindlimb

The inertial sensor system detected lameness sooner than the consensus of equine practitioners regardless of whether the lameness was induced in a forelimb (P<0.001) or a hindlimb (P<0.001). In horses with induced forelimb lameness, the evaluators selected the limb with induced lameness before the inertial sensor system in 1 of 30 (3.3%) lameness inductions. The inertial sensor system identified the limb with induced lameness before the evaluators in 15 of 30 (50%) lameness inductions. The evaluators and the inertial sensor system identified the limb with induced lameness simultaneously in 14 of 30 (46.7%) lameness inductions. The proportion of lameness inductions picked correctly first by the evaluators was less than expected by chance and significantly smaller than the proportion of lameness inductions picked correctly first by the inertial sensor system.
The proportion of lameness inductions in which lameness was detected at the same time by the evaluators and the inertial sensor system was greater than that expected by chance, but not significantly different from the proportion of lameness inductions picked correctly first by the inertial sensors ($P = 0.09$).

In horses with induced hindlimb lameness, the evaluators selected the limb with induced lameness before the inertial sensor system in $4$ of $30$ ($13.3\%$) lameness inductions. The inertial sensor system identified the limb with induced lameness before the evaluators in $20$ of $30$ ($66.7\%$) lameness inductions. The evaluators and the inertial sensor system selected the limb with induced lameness at the same time in $6$ of $30$ ($20\%$) lameness inductions. The proportion of lameness inductions picked correctly first by the evaluators was less than that expected by chance, which was significantly less than the proportion of lameness inductions picked correctly first by the inertial sensor system ($P < 0.001$). The proportion of lameness inductions in which lameness was detected by the evaluators and the inertial sensor system at the same time was what would be expected by chance, but this was significantly less than the proportion of lameness inductions picked correctly first by the inertial sensor system ($P < 0.001$).

**Toe vs. heel**

The inertial sensor system detected lameness sooner than the consensus of $3$ equine practitioners regardless of whether the lameness was induced in the toe ($P = 0.001$) or the heel ($P = 0.001$).

**Discussion**

The wireless inertial sensor system was able to identify induced lameness after significantly fewer half turns of the screw, which corresponded to a lower level of sole pressure, than the consensus of $3$ equine veterinarians. The inertial sensor system correctly identified the selected limb before the consensus of subjective evaluators for both fore- and hindlimb lameness.

This is the first study investigating the sensitivity of a wireless inertial sensor system relative to traditional subjective lameness examination for the detection of induced lameness. Other forms of objective evaluation have been demonstrated to have a greater sensitivity than subjective evaluation, especially with mild lameness [5,19]. A previous study compared traditional subjective lameness evaluation and simultaneous kinematic analysis of horses with navicular disease before and after palmar digital nerve blocks. The evaluators assessed video tapes of the horses moving on a treadmill and were unaware that nerve blocks might have been performed on some of the horses. There was poor interobserver agreement for a change in lameness scale after blocks. However, differences in gait were determined with kinematic analysis [5]. Another study correlating kinetic data and subjective lameness assessment in horses with lameness induced by intra-articular lipopolysaccharide injection demonstrated significant changes in vertical peak force, impulse and stance time from baseline in horses that were subjectively assessed to be sound [19]. Additional studies that have assessed subjective evaluation of equine lameness report an interobserver agreement that is acceptable for moderate lameness but poor for mild lameness, and especially for hindlimb lameness [2-5]. This supports the use of objective lameness evaluation for assessment of mild equine lameness. The wireless inertial sensor system used in this study has been previously reported to have good correlation with simultaneous kinematic analysis of horses with induced and natural lameness moving on a treadmill, suggesting that it is a useful method of objective lameness assessment [15]. This was further supported by the results of the current study, which suggest that the wireless inertial sensor system would be useful in identifying mild lameness in horses moving naturally over ground.

Higher sensitivity of the inertial sensor system at detecting mild lameness compared to observation is probably the result of higher sampling frequency ($200$ Hz) compared with temporal resolution of the unaided human eye ($15-20$ Hz) [20]. Small differences in movement between the left and right halves of the stride due to mild lameness may not be consistently detectable by simple observation.

In this study, $3$ equine practitioners performed the subjective lameness assessment and all $3$ evaluators had to select the correct limb in which lameness was being induced. This could have occurred simply by chance. A consensus of at least $3$ evaluators was required to minimise the influence of chance agreement between evaluators in the results. After $6$ half turns of the screw, the resulting median endpoint for successful subjective evaluation consensus in this study, the likelihood that $3$ evaluators would all select the correct limb by chance alone was $9.5\%$. This is very close to the percentage of trials in which subjective evaluation picked the correct lame limb before the inertial sensors. In this study design, if only $2$ evaluators were required to agree on the correct limb, it could be expected that $32\%$ of the trials would have achieved the subjective evaluation endpoint, by chance alone, after repeat trials.

There were some limitations to the study. Some of the horses required multiple half turns of the screw before either a subjective consensus was reached or before lameness was detected with the inertial sensors. Because the evaluators understood that the trials would continue until they all agreed, evaluators may have second guessed their initial correct selection and switched to a different limb. This may have delayed the consensus and worked against the sensitivity of the subjective evaluators.

On the other hand, the evaluators were aware of the study protocol and knew that the horse would become lame. They had only to indicate the lame limb, as opposed to a normal lameness examination, in which it is uncertain whether or not the horse is lame. This knowledge may have prompted the evaluators to guess or pick a limb before lameness was consistently noticeable. The evaluators were also able to repeatedly evaluate the horse while subtle signs of lameness became more apparent, a situation unlike that in a normal clinical setting. In a normal clinical setting, the veterinarian does not have the advantage of seeing how an individual horse moves when it is sound and then evaluating the horse as it gradually develops a lameness. The evaluators had more chances of seeing subtle changes in the way a particular horse moved and identifying the lameness than a veterinarian would normally have by evaluating the horse in a clinical examination, in which the degree of lameness may not worsen progressively. In addition, the evaluators could compile their $2$ evaluations per trial to help select the correct limb. This was not the case with the inertial sensor system, as both evaluations per trial had to be evaluated as ‘lame’. In addition, the determination of subjective consensus was liberal, and the determination of lameness with the inertial sensors was conservative. This was especially true of the condition requiring the standard deviation to be below the absolute value of the mindiff or maxdiff. Excitable behaviour causing head tossing by the horse will increase the standard deviation for the trial such that it would not meet the conditions for the inertial sensor system to correctly identify lameness even if the other $2$ conditions were met by large margins. In this study, the evaluators did not have to agree on the severity of lameness. They could make a selection based on a few strides per trial, but the inertial sensor system had to have all $3$ variables above threshold for both evaluations per trial. If a horse only had a few lame strides in one of the evaluations, this might have been enough for the subjective evaluators to identify the correct limb. However, a few lame strides per evaluation may not cause the inertial sensor lameness variables, which are based on the mean and standard deviations of all strides in an evaluation, to be above threshold.

There were $5$ instances where the evaluators identified the induced lameness before the inertial sensor system. In $2$ of these instances, $2$ of the $3$ criteria for lameness identification by the wireless sensor system were met, but the standard deviation of the minimum or maximum pelvic height was greater than the mean in at least one of the trials. Thus there was high variability in these trials. In $2$ other instances, all criteria for the wireless inertial sensor system were met for one but not both evaluations in a trial. In the remaining instance only the $a1/a2$ ratio was above threshold. It is possible that evaluation of a parameter not measured by the inertial sensor system (such as stride length or fetlock extension), but evaluated visually by the subjective evaluators, could have enabled the subjective evaluators to reach a consensus before the inertial sensor system.

In one lameness induction neither the equine veterinary evaluators nor the wireless inertial sensor system identified the limb with induced lameness and this lameness induction was considered a tie. This was due to the behaviour of the horse during one lameness induction. The horse was excitable on this occasion, repeatedly tossing her head, bucking, and trying to run away with the handler. Despite tightening the screw as far as
possible, consistent lameness was not identified by the wireless inertial sensor system and consensus was not reached by the evaluators. The horse was, however, successfully evaluated at 3 other lameness inductions without incident.

The use of progressively increasing sole pressure to induce lameness resulted in progressive worsening of lameness in the selected limb. The lameness resolved once the screw had been removed. This model of lameness induction was ideal for this type of study but may not be ideal for use in other lameness studies. There was variation in the response of individual horses to sole pressure. Some horses were very sensitive and would rapidly develop lameness with small amounts of sole pressure, and other horses required a greater amount of sole pressure to demonstrate lameness. Degree of lameness between horses could not be predicted by amount of sole pressure; however, individual horses showed increasing lameness with gradually increasing sole pressure. A lameness induction model that produces the same amplitude of lameness in every horse and that can then be gradually worsened with precise increase in application has not been described. This study used horses with induced lameness. Further investigation would be needed to assess whether the same results would be found in horses with naturally occurring lameness.

Knowledge of the horse’s history, palpation of the limbs, and the performance of a complete lameness examination involving evaluation of the horse on the lunge and flexion tests may improve the sensitivity of the subjective lameness assessment. In this study the degree of lameness first detected by the inertial sensor system can only be inferred from the results of the subjective evaluation of the horse trotting in a straight line. It can be inferred that the lameness severity would not be consistently seen by the human eye, since a lameness of this severity would have been expected to be picked up consistently by all 3 evaluators. This study also only evaluated horses with lameness induced in one limb, thus these results are not necessarily transferable to horses with multiple limb involvement, which is common clinically. Further research is needed to assess the ability of the inertial sensor system to identify multiple limb lameness. Additional research on the usefulness of the inertial sensor system for identifying response to local anaesthesia or for identifying changes in lameness over time or in response to specific treatments would increase its clinical application.

In conclusion, the wireless inertial sensor system of lameness evaluation in horses identified induced lameness at a significantly lower level of sole pressure, and was therefore more sensitive than the consensus of 3 equine veterinarians. Data collection was live and data analysis was achieved within a few seconds. The system was easy to use and would probably be valuable in the evaluation of clinical lameness in horses.

Conflicts of interest

Dr Keegan founded Equinosis LLC, which sells the inertial sensor system (Lameness Locator), which was evaluated in this study. Dr Keegan is a co-inventor of Lameness Locator and a minority stakeholder in Equinosis.

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Manufacturer’s address

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References


